1.0

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

Contract No. N61339-79-C-0011, Mod. No. P00007

FIRE FIGHTER TRAINER ENVIRONMENTAL CONSIDERATIONS
PHASE II

Booz, Allen & Hamilton Inc.
4550 Montgomery Avenue
Bethesda, Maryland 20014

31 July 1981

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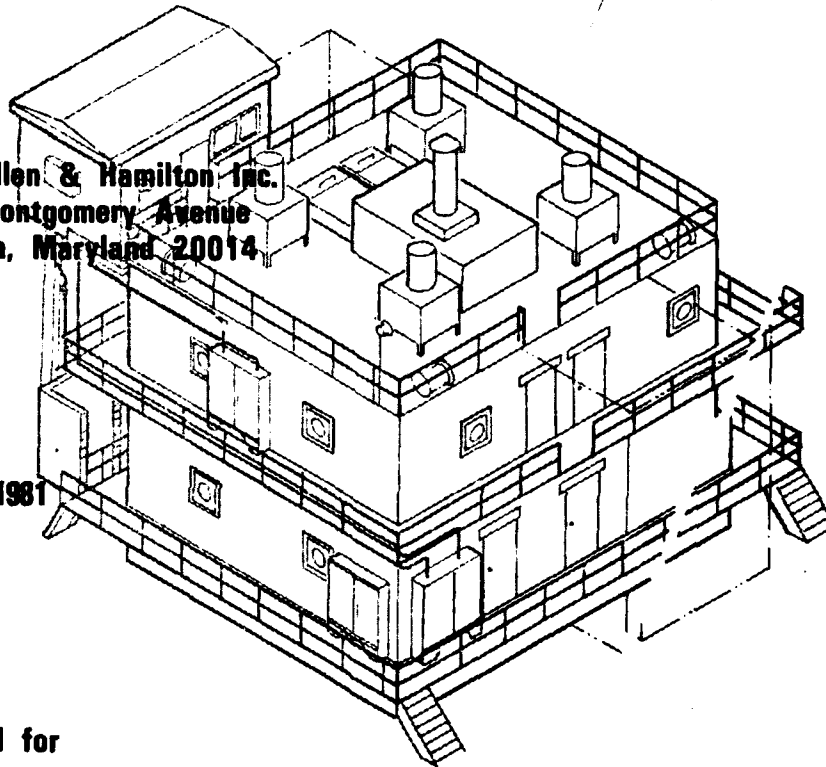
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1.   INTRODUCTION

This report presents the results of the second phase of a two-phase effort to evaluate the environmental, health, and safety aspects of the U.S. Navy's Advanced Fire Fighter Trainer (AFFT).

Naval fire fighter training is currently conducted at shore-based facilities by burning fossil fuels with the associated adverse environmental impacts. In an effort to upgrade their training techniques, the Naval Education and Training Command, through the Naval Training Equipment Center (NTEC), is conducting a program to provide more effective fire fighter training through the development of the AFFT. The AFFT simulates Class A, B, C, and D fires under different but controlled conditions in a training environment resembling shipboard conditions.

The AFFT must provide simulated fire conditions and be able to measure fire-fighting reaction, as well as be operationally acceptable in terms of:

. 1   Environmental considerations such as air emissions, wastewater effluents and solid waste disposal in order to comply with Navy, Federal, state, and local requirements and

. 2 Health and safety considerations that include the effects of combustion products emissions on the life sustaining capabilities of the AFFT atmosphere, possible toxicity of all products used and produced during AFFT operation, and use of a modified oxygen-breathing apparatus (OBA).

Advanced Technology Systems (ATS), a division of the Austin Company, has installed a prototype AFFT (Model 19F1) at the Navy Fire Fighter Training School in Norfolk, Virginia (NORVA) in an existing training structure. Subsequent production units will be installed in structures specifically designed for the AFFT by the Naval Facilities Engineering Command.

1.1 Background. The environmental, health, and safety evaluation of the AFFT was carried out in two phases. The first phase was designed to provide a preliminary definition of conditions in the 19F1 by:

    .   Defining the planned 19F1 utilization

    .   Identifying environmental, health, and safety constraints

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- Estimating the degree of environmental hazard through limited onsite sampling and analysis

- Identifying potential areas for trainer redesign and modification necessary for operating within the constraints

- Evaluating acceptability of the modified OBA.

The conclusions and recommendations from the Phase I final report are summarized as follows:

- Regulatory constraints of five government bodies apply to the 19F1. Complete compliance with the strictest criteria was recommended.

- The internal environment of the 19F1 is hazardous due to the extreme heat and inhalation exposure of toxic materials. All personnel should wear protective equipment and special attention should be given to the instructors who will generally be at greatest risk.

- Propylene glycol fog has a high potential for uncontrolled combustion or explosion under open-flame conditions. Propylene glycol should not be used in the 19F1 AFFT.

- There is a potential for the accumulation and explosion of propane. Further testing is needed to determine the extent of this potential. Redesigning the ventilation system should be considered.

- The 19F1 probably will not meet requirements for air emissions, wastewater effluents, and solid waste disposal. A detailed characterization should be made of air emissions, wastewater, and OBA canister waste.

- Recycling of the grey water is not practical at this time. Procedures for proper treatment and disposal should be followed. Treatment wastes may need special handling.

- Materials used in the 19F1 have exhibited considerable incompatibility. Substitutes for the aqueous film-forming foam (AFFF) and purple K powder/potassium bicarbonate (PKP) should be pursued vigorously.

- The modified OBA does not provide the necessary respiratory protection. Continued use of the standard OBA is strongly recommended.

1.2 <u>Purpose of this study</u>. This study phase completes the definition of environmental, health, and safety conditions associated with the 19F1 AFFT. Many of the problems identified in the first phase study can be resolved through identifying substitutes for AFFF, PKP, and propylene glycol. This was the main objective of the second phase effort. Additional objectives of the assignment included:

- Define the major environmental conditions within the operating 19F1 trainer and establish requirements for modification and redesign

- Evaluate and recommend substitutes for extinguishments and simulated smoke

- Characterize air emissions and water effluents and identify requirements for environmental permits.

These objectives were accomplished by using the following methods:

- Screening, characterization, and limited laboratory analyses of candidate substitutes for AFFF, PKP, and propylene glycol

- Onsite testing of selected substitutes with sampling and laboratory analysis of air emissions and water effluents

- Determining interior temperature profiles

- Assessment of CO, CO_2, O_2 and flammable gas concentrations

- Measuring concentrations of simulated smoke.

These task objectives are presented in Figure 1.
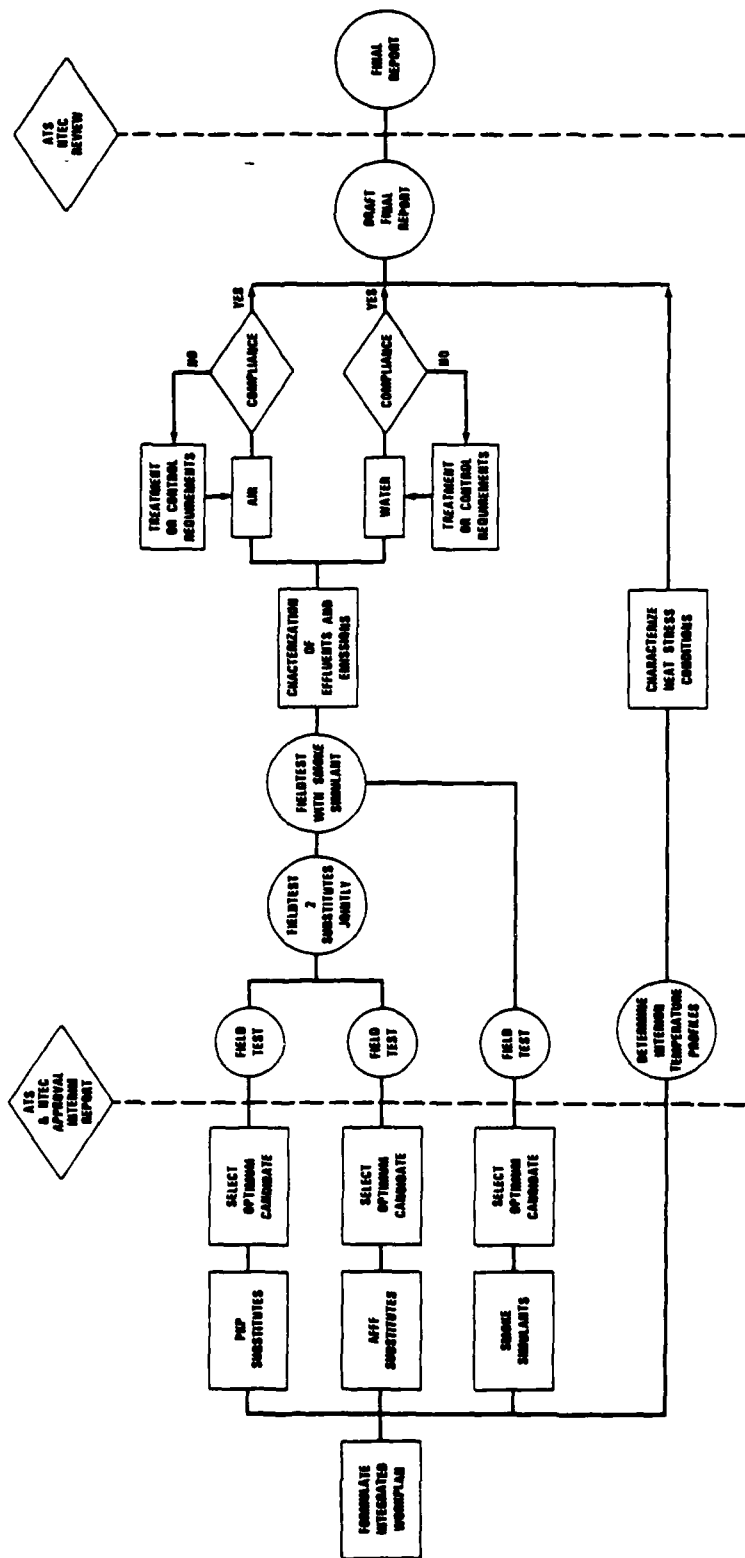
Figure 1. Phase II Task Objectives

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2.   MODIFIED 19F1 TRAINING SYSTEM DESCRIPTION

This chapter presents a detailed description of the 19F1 trainer facility, including the building itself; the various fireplaces; the extinguishment detector system; and the air quality monitoring, control, and communications systems. A discussion is also presented concerning the process by which candidate substitute extinguishment agents were evaluated to replace the previously used AFFF (aqueous film-forming foam), PKP (purple K powder/potassium bicarbonate), and propylene glycol.

2.1   19F1 prototype system description.   The 19F1 prototype fire fighter trainer is located in Building No. 8 at NORVA, as shown in Figure 2.   The structure is divided into four quadrants.   Each quadrant is exhausted by a 5,000-cfm axial fan that draws air from beneath the building up through steel gratings that comprise the decks of both levels.   Presently, 5 out of approximately 15 planned shipboard fire simulators or fireplaces have been installed on the upper deck of Quadrant II (UDQII) and on the lower deck of Quadrant I (LDQI), as shown in Figure 3.

Originally, the exhaust fans were programmed to activate during the 3-minute preventilation period following turn-on. After 3 minutes, the fans stopped automatically but were programmed to reactivate when any emergency shutdown switch was activated or when the propane concentrations in active compartments were greater than 10 percent of that which could ignite from any free gas within the quadrant [lower explosive limit (LEL)].   However, the exhaust fans were set to operate continuously during all Phase II tests for the reasons outlined in Section 5.3.1 of this report.

The instructor control station is located on the top deck of the training structure.   The station contains the fire simulator control panel, the structure control panel, communication and alarm controls, air quality and audiomonitoring controls, and the instructor communications system.

Five fireplace simulators used to represent shipboard fires include oil spray and bilge fire, electrical fire, rag bale fire, and deep fat fryer and stack hood fire.   These five simulators, which are presented in Figures 4 through 7, are equipped with propane burners to simulate each type of fire.

Different fireplaces require different size flames, and these flames must be varied in size to give the appearance of growing and spreading.   The controller provides this function
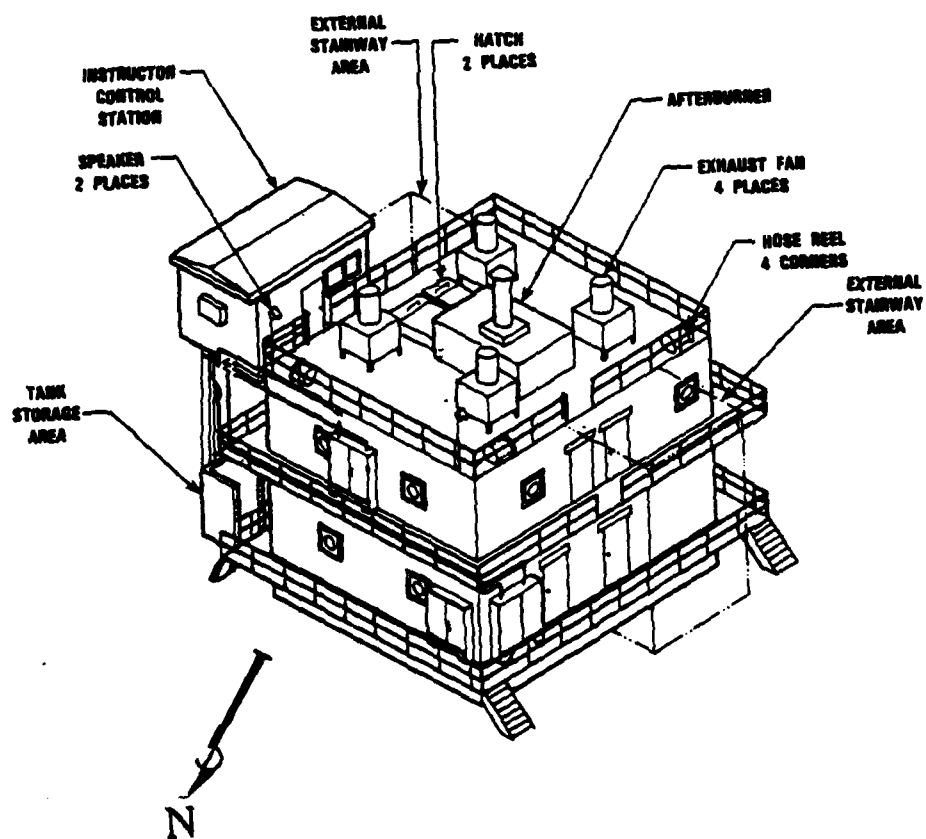
Figure 2. 19F1 Training Structure

CONTROL ROOM

UDQII

RAG BALE

DEEP FAT FRYER

OIL SPRAY/ BILGE

ELECTRICAL PANEL

LDQI
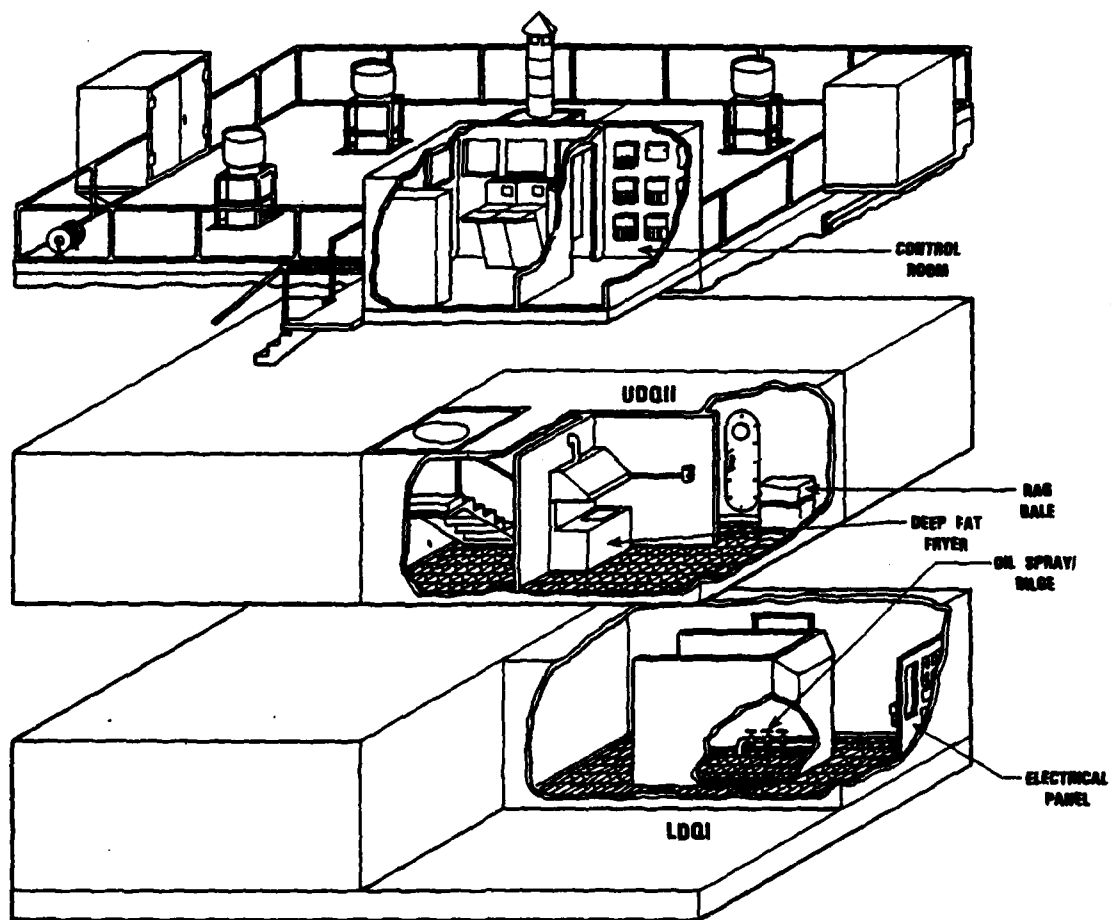
Figure 3.   Advanced Fire Fighter Trainer

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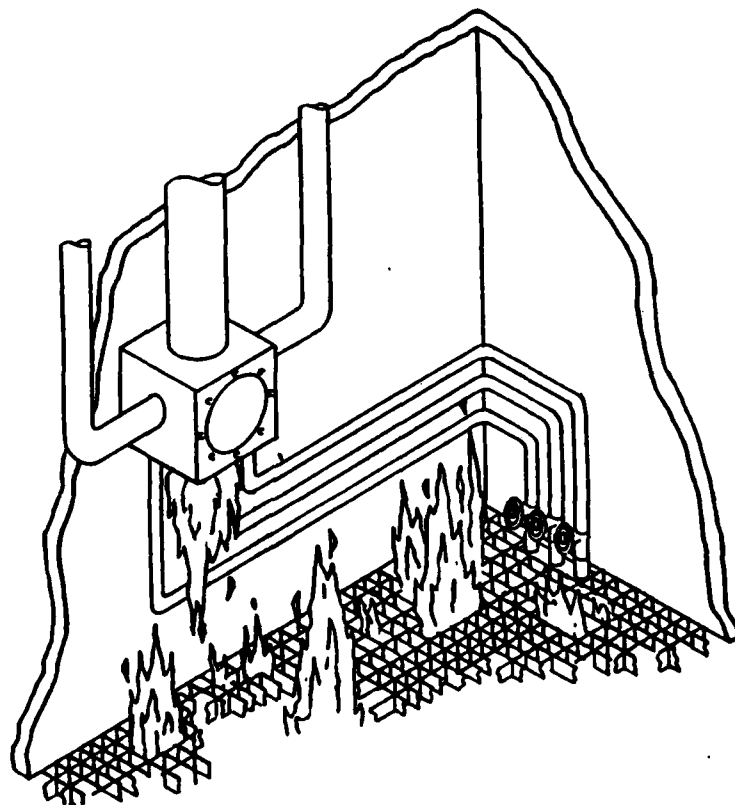
Figure 4. Oil Spray/Bilge Fireplace
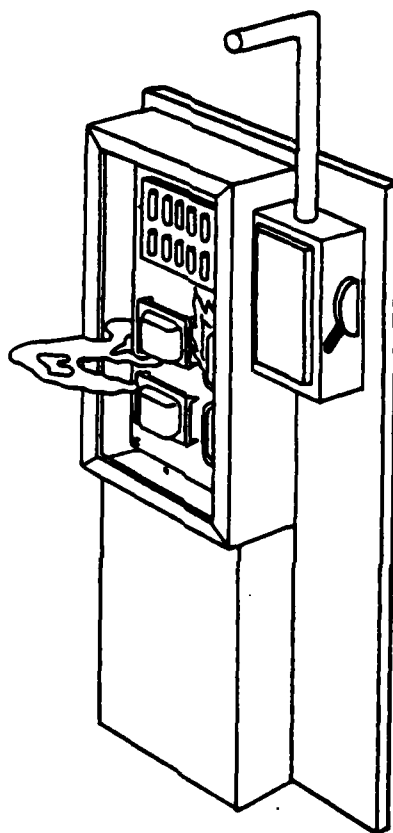
Figure 5.   Electrical Panel Fireplace
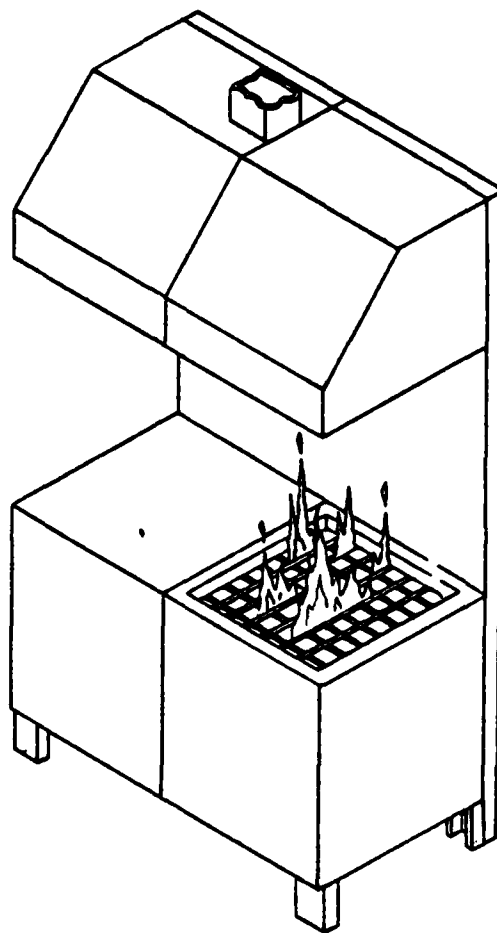
Figure 6.   Deep Fat/Stack Hood Fryer
Fireplace
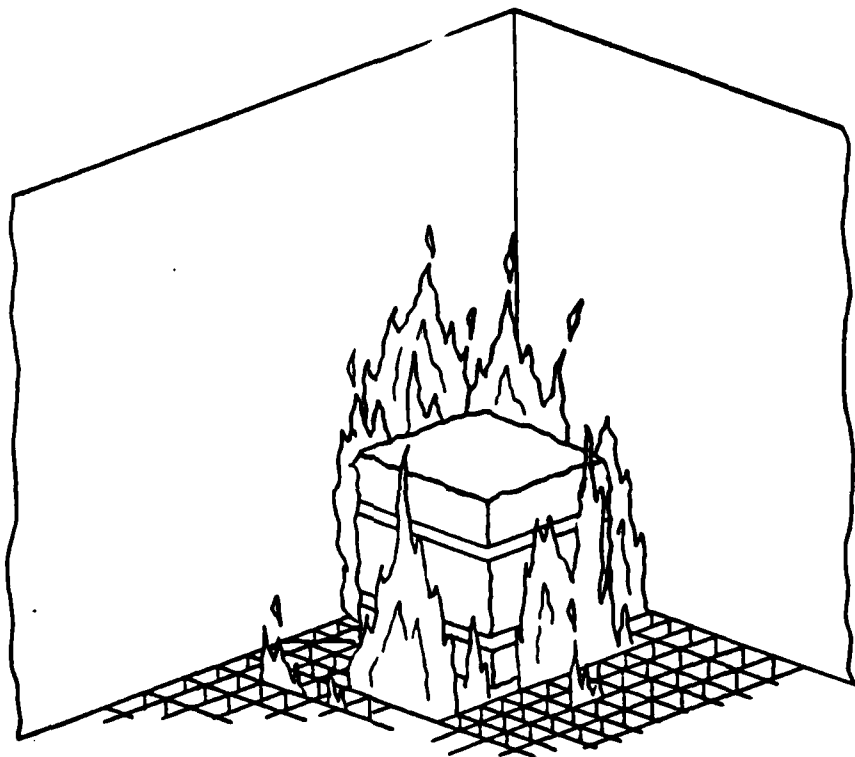
Figure 7.   Rag Bale Fireplace

through modulated valves on each burner. Nonextinguishable pilot flames are on at all times during the exercises. To simulate a natural fire, the air/propane ratio in the burners is normally maintained at 10:1 to provide a yellow flame.

The 19F1 simulator will use several types of extinguishing agents—water, CO_2, powder, and foam. The agents PKP and AFFF that were used during Phase I of this project are being replaced with appropriate substitutes to be used as their surrogates in training. Simulated smoke is generated by heating triarylphosphate (TAP) in a TIFA Fogging Machine. All of these agents are discussed more fully in subsequent chapters. The extinguishing agents used in each fireplace are shown in Table 1.

To achieve the appearance of extinguishing the fire, each fireplace is equipped with an extinguishment sensor system to detect the application and location of the agent being applied. The system will differentiate between the application of water, powder, and foam directly on the fire through liquid level sensors, ultraviolet flame detectors, and retroreflective-pulsed LED photodetectors. These sensors respond to the various actions of sweeping the extinguishing agent over the simulated area of fire. Output signals from the extinguishing agent sensors are sent to the programmable controller to control the fire-generation equipment for appropriate flame responses.

Realism is achieved through placement of the burners and sensors and through the time delays for reaction to extinguishments, reignition (the interaction of adjacent burners to produce flame spread over an area), and torching (a rapid flame growth resulting from applying a solid stream of water in a "digging" fashion).

An air quality/fire-effluent-monitoring system is used to detect unacceptable levels of O_2, CO_2, CO, NO, and hydrocarbons. A fire-effluent air sampling intake is located at the entrance to each of the two roof exhaust fans in the training facility. An air-quality sampling intake is also located in each compartment.

Operation of the training structure's exhaust system is governed by start-up procedures, manual shutdown, and gas detection. Start-up procedures and manual shutdown functions of the exhaust system are programmed into the controller. Function of the exhaust system for gas detection requires that unacceptable gas levels be detected by the air-quality analyzer.

TABLE 1.   EXTINGUISHING AGENTS USED
IN EACH FIREPLACE

Fireplace	Water	Foam	Powder	CO_2
Bilge	X	X	X	
Oil Spray	X	X	X	
Rag Bale	X	X		
Electrical Panel				X
Deep Fat Fryer	X		X	
Stack Hood	X		X	
Deep Fat Fryer/ Stack Hood	X		X	

Activation and control of the 19F1 trainer is initiated at the instructor console. The control-system interface is shown in the schematic presented in Figure 8. The system contains all of the controls and indicators necessary to initiate a fire and establish the growth, spread, and reflash rates as well as the soaking and extinguishment time periods for the fire. By adjusting these parameters, the instructor can simulate realistic fire emergencies for various classes of combustible materials. Alarms and indicators are provided to monitor fire status and alert the instructor to any hazardous conditions in the fire simulator or training area.

All fire-generation and control signals from the instructor console are routed through a programmable controller. The controller scans all inputs from the console and establishes whether the input status meets the circuit conditions stored in memory. Based on the input status and stored circuit conditions, the controller generates the appropriate output signals to the various trainer units. The output signals control the motorized valves, solenoids, relays, and electronic units used to simulate the appropriate fire conditions. As the training exercise progresses and trainee interaction occurs (the application of extinguishment), the extinguishment sensor system detects the extinguishment application and feeds such data back to the Square D controller. The Square D controller then processes the feedback data with the entered parameter data and appropriately varies the flame output of the fireplace burners. Thus, the flames seen by the trainees appear to vary as they would if encountered in a real world shipboard fire emergency.

Communications equipment meets military standards where possible and has been modified to work with high-grade commercial equipment where necessary. All operational capabilities for military communications equipment have been retained. Each training compartment has a local communications station with damage-control communications equipment consisting of compartment audiomonitoring microphones, microphone communication links between the instructor station and trainee compartments, and a sound-powered telephone.

2.2 Candidate modifications evaluated in this study. Due to potentially serious environmental, health, and safety problems associated with the use of the original extinguishing agents assessed during Phase I of this study, it was determined that these agents should be replaced with less troublesome products. This section presents the results of an evaluation of suitable substitute foam, powder, and smoke candidates and provides recommendations as to the optimal candidate for each agent based on the evaluation.

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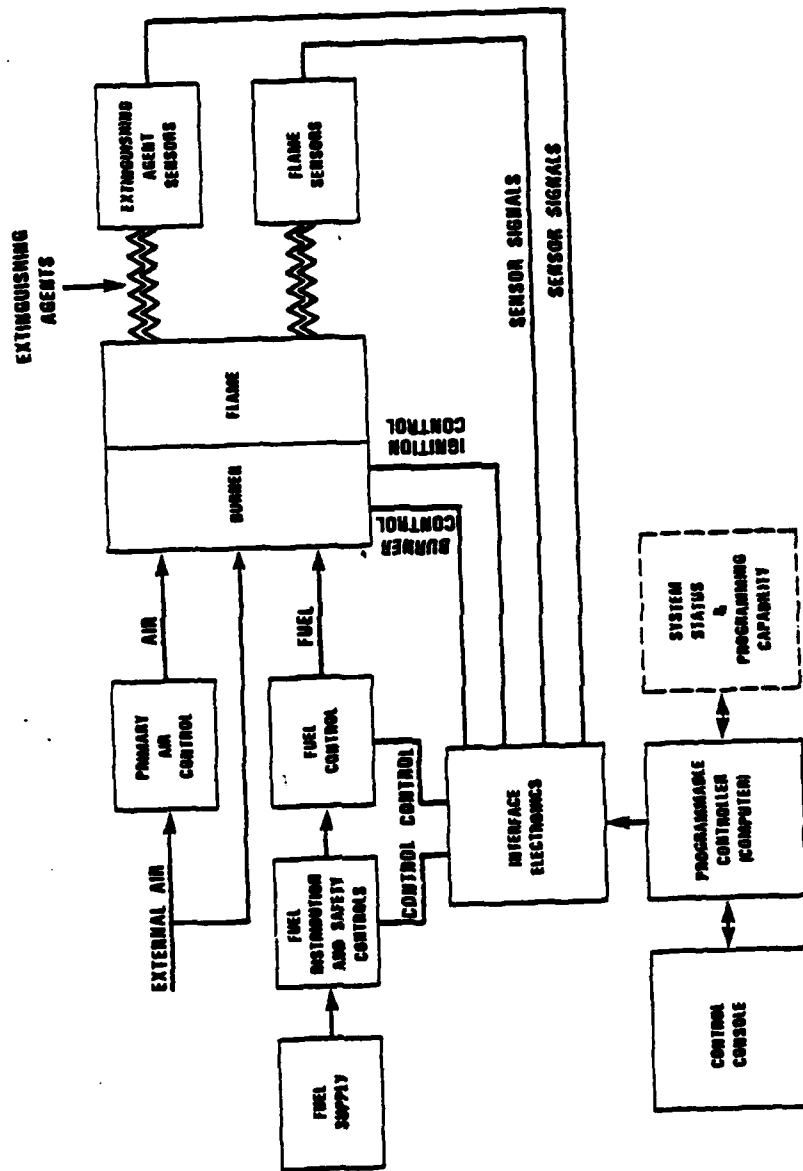
Figure 8. Control-System Interface Schematic

2.2.1 Foam extinguishment substitutes. AFFF, the original extinguishing agent planned for use in the 19F1, has several undesirable features for training purposes as identified in Booz, Allen's Phase I investigation. These undesirable characteristics included the following:

- Relatively high cost

- Requirement for controlled discharge into Publicly Owned Treatment Works (POTWs)
- Potential toxicity of thermal reaction products.

During Phase II of the project, Booz, Allen investigated possible substitute foams for use as an AFFF surrogate with the objective of selecting the two most likely candidates for on-site testing at the Naval training facility in Norfolk, Virginia. To ensure adequate supplies and availability, yearly production and sales of surface active agents produced in the United States were investigated as possible substitutes. Much of this information was obtained from a report entitled, Synthetic Organic Chemicals, United States Production and Sales, 1979 (USITC Publ. 1099, U.S. International Trade Commission, Wash., D.C.). The report contains a comprehensive list of surface active agents, which is presented in Appendix E.

2.2.1.1 Characterization and evaluation criteria. Because there are hundreds of types of surfactants on the market, we selected candidates based on the criteria described in this section.

A suitable substitute candidate for AFFF must be compatible with the flame-control logic of the training device and must be detectable by the current foam sensors (activated by opacity of the applied foam), although it does not need to be a fire extinguishment. Commercial surfactants, identified in the initial study, were surveyed as candidate substitutes based on their potential for meeting the following criteria:

- Readily available in large quantities
- Nonflammable
- Environmentally acceptable

  - Disposable in effluent
  - Biodegradable

- No adverse effects on human health and safety
- Adequate foaming action
- Stability at high temperatures
- Minimally corrosive
- Cost-effective for training.

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In our preliminary evaluation, we considered all major classes and subclasses of surfactants as identified in Appendix E. Because of the large number of possible candidates, we eliminated specific types of surfactants from the detailed evaluation that appeared to have undesirable properties as an AFFF substitute. As indicated in the table in Appendix E, these candidates are divided into four major classes of surface active agents--amphoteric, anionic, cationic, and nonionic. The following sections present our key findings and conclusions for each class of surfactant.

2.2.1.1.1 Amphoteric surfactants. The annual production volume of amphoteric surfactants in 1979 was approximately 20.5 million pounds. This volume is very low compared with the other classes. One major criterion for an AFFF substitute is that it must be readily available in large quantities. The amphoteric surfactants do not meet this criterion; therefore, we eliminated this category from further detailed evaluation.

2.2.1.1.2 Anionic surfactants. The total annual production volume of anionic surfactants in 1979 was approximately 3.2 billion pounds. Subclasses of surfactants that were among the highest in annual production volume for 1979 in this category include the following:

- Phosphoric and polyphosphoric acids (and their salts) - 38 million pounds

- Sulfuric acid esters (and their salts) - 552 million pounds

- Carboxylic acids (and their salts) - 878 million pounds

- Sulfonic acids (and their salts) - 1.6 billion pounds.

Phosphoric and polyphosphoric acids pose a disposal problem because phosphate compounds are environmentally controlled. Because these compounds do not meet the environmental criteria we set for an AFFF substitute, we eliminated this subclass from further consideration.

Sulfuric acid esters have a potential for decomposing with heat to produce toxic vapors (i.e., SO_2 and SO_3) and sulfuric acid (H_2SO_4) in aqueous medium. The potential toxic vapors and acidity from use of these compounds in a firefighting situation do not meet the health and safety criteria for an AFFF substitute; therefore, we eliminated this subclass from further consideration. We included, however, sodium lauryl sulfate (sodium salt) in our more detailed analysis for comparison with other products, although it was not selected for

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testing because of the toxic vapors and acidity described above. An additional potential hazard of sodium lauryl sulfate is that if it becomes anhydrous under fire-fighting conditions, the dry powder is flammable.

The carboxylic acids (and their salts) were preliminarily acceptable according to the criteria. For further evaluation, we selected the subclass of coconut oil acids (sodium salt), which was among the highest in annual production volume for this category (151 million pounds). Specifically, we selected the sodium salt of lauric acid (e.g., Ivory Snow) because of its large production and consumer exposure, which suggested that it is safe to human health and the environment.

The sulfonic acids (and salts) were also preliminarily acceptable according to the criteria. We selected the subclass of alkylbenzene sulfonates, which had a high annual production volume of 552 million pounds in 1979, for further evaluation. Specifically, we selected dodecylbenzene sulfonic acid (sodium salt) for further evaluation because it has the highest production volume (307 million pounds in 1979) of all the surfactants in this subclass.

2.2.1.1.3 Cationic surfactants. The total annual production volume of cationic surfactants was approximately 294 million pounds in 1979. Subclasses of surfactants in this category that were among the highest in production volume for 1979 include the following:

- Amine oxides, amines containing oxygen - 78.3 million pounds
- Amides - 30.2 million pounds
- Amines not containing oxygen - 85.4 million pounds
- Quaternary ammonium salts - 86.6 million pounds.

All of these subclasses have features that are undesirable in an AFFF substitute. They all have relatively low production volumes and produce only low levels of foam. The amines, amine oxides, and amides present disposal problems because they form ammonia in aqueous environments and, hence, in the effluent, which is toxic to aquatic life. In addition, these compounds may react with heat.

Quaternary ammonium compounds also pose a potential disposal problem because they may have a bactericidal action in the effluent and, hence, can interfere with water treatment. These compounds may decompose with heat and, therefore, would not be suitable foams for a fire-fighting situation.

2.2.1.1.4 Nonionic surfactants. The total annual production volume of nonionic surfactants in 1979 was approximately 1.5 billion pounds. Subclasses of surfactants in this category that were among the highest in production volume for 1979 include the following:

- Carboxylic acid amides - 70 million pounds
- Carboxylic acid esters - 254 million pounds
- Ethers - 1.119 billion pounds.

Carboxylic acid amides present disposal problems because they form ammonia in aqueous environments. The presence of ammonia in the effluent is toxic to aquatic life. Hence, this subclass is not acceptable according to the environmental criteria for an AFFF substitute and was eliminated from further consideration.

The carboxylic acid esters were preliminarily acceptable according to the criteria. From this subclass, we selected polyethylene glycol esters for further evaluation because they were among the highest in production volume for this category (48.1 million pounds in 1979).

The subclass of ethers was also preliminarily acceptable to the criteria for an AFFF substitute. We selected candidates for further evaluation from the two main groups of this subclass -- benzenoid ethers and nonbenzenoid ethers. The production volumes for these groups in 1979 were 433 and 646 million pounds, respectively. For the detailed evaluation we selected the ethoxylated nonylphenols and ethoxylated octylphenols from the benzenoid ethers group (annual production volumes in 1979 were 308 million pounds and 2.8 million pounds, respectively). From the nonbenzenoid ethers group, we selected candidates from the ethoxylated mixed linear alcohols, which had an annual production volume of 567 million pounds in 1979.

2.2.1.1.5 Other foams. In addition to the surfactants listed in Appendix E, we also considered protein hydrolysates and high-expansion foams. These candidates, however, have features that are undesirable as an AFFF substitute. The protein hydrolysates have a noxious odor and are unstable compounds with a poor shelf life. They also contain zinc, which is environmentally controlled. Because these compounds do not meet the environmental criteria that we set for an AFFF substitute, we eliminated them from further consideration.

High-expansion foams require delivery with specialized equipment that is not used by the current fire fighter trainer. In addition, these foams do not dissipate easily and quickly. Therefore, they were considered unsuitable for the proposed training scenarios and were eliminated from further consideration.

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2.2.1.1.6 Summary of foams eliminated from further consideration. In summary, we eliminated those surfactants from detailed evaluation that appeared to have undesirable properties as an AFFF substitute. These candidates and the basis for their elimination follow:

- Amines, amine oxides, amides, imides--relatively small production volumes; disposal problems; possibility of reaction with heat

- Phosphate compounds--disposal problems (environmentally controlled)

- Quaternary ammonium compounds and other cationic surfactants--low-foam producers; possibility of physiological action (e.g., bactericidal action) in effluent and of decomposition with heat

- Sulfate esters--possibility of decomposition with heat to produce toxic vapors (i.e., SO_2 and SO_3, H_2SO_4 in aqueous medium)

- Protein hydrolysates--contain zinc (environmentally controlled); unstable (poor shelf life); noxious odor

- High-expansion foams--must be delivered with specialized equipment; foam does not dissipate easily and quickly and is therefore not suitable to the currently proposed training scenarios.

Although a viable candidate, we did not select sodium lauryl sulfate for testing because it produces toxic vapors of sulfur oxides that are acidic in aqueous medium (sulfuric acid). If it becomes anhydrous under fire-fighting conditions, the dry material is flammable.

2.2.1.1.7 Candidate foams selected for further evaluation. Several candidates were evaluated in greater detail as potential substitutes for AFFF. These candidates, which include alkylbenzene sulfonates and nonionic surfactants, are commercially available in large quantities and generally meet the other previously established criteria. We have considered many widely used products from these types of surfactants that have known properties that might conform to the criteria. The following list of candidates contains specific product names and manufacturers. Although the generic products are commercially available from many manufacturers, we are listing the specific manufacturers who cooperated by providing data on their products.

- Ethoxylated straight-chain alcohols

  - Neodol 25-7 (Shell Oil Company)
  - Neodol 25-12 (Shell Oil Company)
  - Tergitol 15-S-7 (Union Carbide)
  - Tergitol 15-S-12 (Union Carbide)
  - Tergitol 25-L-7 (Union Carbide)
  - Tergitol 25-L-12 (Union Carbide)

- Ethoxylated octyl or nonyl phenols

  - Triton X-100 (Rohm and Haas)
  - Triton N-101 (Rohm and Haas)
  - Tergitol NP-9 (Union Carbide)
  - Tergitol NP-10 (Union Carbide)

- Linear alkylbenzene sulfonates

  - Ultrawet K (Arco)
  - Nacconol 35 SL (Stepan)

- Polyethylene glycols (foam stabilizers)

  - Polyox WSR-N 10 (Union Carbide)
  - Pluronic P-94 (BASF-Wyandotte)

- Soap (sodium salt of lauric acid)

  - Ivory Snow (Proctor and Gamble)

- Sodium lauryl sulfate

  - Maprofix 563 (Onyx Chemical Company).

2.2.1.2 Evaluation of utility and environmental safety.
The suitability of candidate foams as substitutes for AFFF was
evaluated according to specific criteria using information
available from the manufacturers and other reference material.
The specific criteria for evaluation and selection of the two
most likely candidates for onsite testing included the follow-
ing:

- Production volume - indicates if the foam is readily
  available in large quantities

- Nonflammability - indicates if the surfactant will not
  burn during use as a fire-fighting extinguishment

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- Environmental factors

    - Disposability in effluent – indicates if the
      large quantities of foam used in the training
      scenarios can be flushed out of the trainer and
      safely disposed into the effluent (e.g., compat-
      ible with water treatment)

    - Biodegradability – indicates if the foam in the
      effluent is biodegradable

    - Aquatic toxicity – indicates if the foam in the
      effluent is safe to aquatic life.

- Thermal decomposition products – indicates the pro-
  ducts released if the foam decomposes in the heat of
  the fire-fighting environment

- Detectability by sensors – indicates if the opacity of
  the applied foam is sufficient to activate the current
  foam sensors in the trainer

- Foam quantity

    - Indicates if the surfactant solution forms a
      high, moderate, or low quantity of foam, which is
      conventionally defined as described in a U.S.
      patent (No. 3,578,590, p.2)

    - Defined as a ratio of foam volume generated from
      one volume of concentrated liquid soap solution,
      as follows:

        .. High foam: 100 to 1,000 x initial volume of
           concentrated soap solution

        .. Moderate foam: 10 to 100 x initial volume of
           concentrated soap solution

        .. Low foam: 1 to 10 x initial volume of con-
           centrated soap solution

- Effect of heat on foam – indicates if the foaming
  action will be constant even at high temperatures as
  encountered in the fire fighter trainer

- Dischargeability with current equipment – indicates if
  foam can be discharged into the fire using currently
  available equipment in the trainer

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. Human and animal toxicity data - indicates if use of the foam in the trainer is relatively nontoxic to the fire fighter

. Corrosion potential - indicates if use of the foam will cause relatively little corrosion of the trainer and equipment

. Cost - indicates if the foam is relatively inexpensive per pound.

The evaluation of each candidate foam according to these criteria is discussed in the following sections. Our initial assumption was that all of these candidates would produce a foam that is both dischargeable with current equipment and detectable by the sensors. Subsequent to this evaluation, we would rank the foams according to the other criteria and then perform field tests on the selected candidates to verify these assumptions. We also recognize that concentrated surfactants are toxic. In the evaluation, we discuss relative nontoxicity based on the realization that the foam used in the trainer will be a very dilute solution. The information available on the criteria for each candidate in this phase of the evaluation is summarized in Tables 2 and 3. Although the criteria in these tables are presented as primary and secondary criteria, all of the criteria were integrated for the evaluation.

2.2.1.2.1 Sodium dodecyl benzene sulfonate. Two products that we evaluated containing sodium dodecyl benzene sulfonate were Ultrawet K (Arco) and Nacconal 35 SL (Stepan). These surfactants (apparently identical products) are produced in high volumes (307 million pounds in 1979) and are inexpensive ($0.32 per pound in 1979; see Appendix E). They are relatively nontoxic to humans. Preliminary tests indicated that these products produce a high quantity of foam that does not dissipate at high temperatures. The surfactant is nonflammable. There is no information available on the corrosion potential of the foam.

The foam is biodegradable; however, all foams are toxic to aquatic life and cannot be directly discharged into natural waters. The foam can be discharged into a POTW if it meets the standards of the POTW.

Although the thermal decomposition products of the dry surfactant powders could involve toxic oxides of sulfur, preliminary tests indicated that aqueous solutions as would be used in the fire fighter trainer were not readily dehydrated by heat. In our limited laboratory analysis, we heated an aqueous

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PRIMARY CRITERIA	SODIUM DODECYL BENZENE SULFONATE (ULTRAWET K, SACCONOL 35 SL)	ETHOXYLATED OCTYL PHENOL (TRITON X-100)	ETHOXYLATED NONYL PHENOLS (TRITON N-101)	(TERGITOL NP-9 NP-10)	ETHOXYLATED STRAIGHT CHAIN ALCOHOLS (TERGITOL 25-L-7)	(TERGITOL 25-L-12)	(TERGITOL 15-S-7)	(TERGITOL 15-S-12)
1. PRODUCTION VOLUME (MILLION LBS/YR)	217	<2.0	38		60? (ALL 25-L SERIES)	60? (ALL 25-L SERIES)		
2. FLAMMABILITY (FLASH POINT °F)	NONE (NONE)	NONE (>300)	NONE (>300)	NONE	(340)	(412)		
3. ENVIRONMENTAL FACTORS & DISPOSABILITY IN EFFLUENT	FOAM	FOAM	FOAM	FOAM	FOAM (≥30 PPM)	FOAM (≥30 PPM)	FOAM	FOAM
(ii) BIODEGRADABILITY	YES	YES	YES	YES	YES	YES	YES	YES
(iii) AQUATIC TOXICITY (MG/L) [1]		10-12 (BLUEGILL)		13.5 (AVERAGE) (1.6-24) (FATHEAD MINNOW)	16 (FATHEAD MINNOW)	10 (FATHEAD MINNOW)	2.7 (FATHEAD MINNOW)	3.2 (FATHEAD MINNOW)
4. THERMAL DECOMPOSITION PRODUCTS	CO_2 + H_2O +CO + OXIDES OF SULFUR + H_2S TEST FOR OUTGASSING SLIGHTLY ACIDIC (H_2SO_4)	CO_2 + H_2O + CO	CO_2 + H_2O + CO	CO_2 + H_2O + CO	CO_2 + H_2O + CO + ALDEHYDES, ACIDS	CO_2 + H_2O + CO + ALDEHYDES, ACIDS	CO_2 + H_2O + CO + ALDEHYDES, ACIDS	CO_2 + H_2O + CO + ALDEHYDES, ACIDS
5. DETECTABLE BY SENSORS								

[1] Higher values indicate relatively lower toxicity. EPA acceptable level is 500 mg/l.

TABLE 2. PRIMARY FOAMS
CRITERIA/EVALUATION

ETHYLATED STRAIGHT CHAIN ALCOHOLS				SODIUM LAURYL SULFATE	SOAP-LAURIC ACID, SODIUM SALT	POLYETHYLENE GLYCOLS	
(EOL 15-S-7)	(TERGITOL 15-S-12)	(NEODOL 25-7)	(NEODOL 25-12)	(SIAPROFIX ?)	(IVORY SNOW)	(POLYOX WSR-N 10)	(PLURONIC P-94)
				28	101		
		YES	YES	YES FLAMMABLE AS DRY POWDER	NONE		NONE (>400)
FOAM	FOAM	FOAM (+ GEL) KEEP OUT OF SEWERS AND PUBLIC WATER SYSTEMS USE LANDFILL OR INCINERATION	FOAM (+ GEL) KEEP OUT OF SEWERS AND PUBLIC WATER SYSTEMS USE LANDFILL OR INCINERATION	FOAM	FOAM	NOT A FOAM (STABILIZER)	NOT A FOAM (STABILIZER) DISPOSABLE IN SMALL AMOUNTS
YES	YES	YES	YES	YES	YES	YES	YES
3.7 (FATHEAD MINNOW)	3.2 (FATHEAD MINNOW)						
$CO_2 + CO$ YDES, ACIDS	$CO_2 + H_2O + CO$ + ALDEHYDES, ACIDS			ACIDIC VAPORS (PROBABLY OXIDES OF SULFUR)	$CO_2 + H_2O + CO$	$CO_2 + H_2O + CO$ + ALDEHYDES, ACIDS	$CO_2 + H_2O + CO$

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SECONDARY CRITERIA	SODIUM DODECYL BENZENE SULFONATE (ULTRAWET K, BACCONOL 35 SL)	ETHOXYLATED OCTYL PHENOL (TRITON X-100)	ETHOXYLATED NONYL PHENOLS		ETHOXYLATED STRAIGHT CHAIN ALCOHOLS			
			(TRITON N-101)	(TERGITOL NP-9 NP-10)	(TERGITOL 25-L-7)	(TERGITOL 25-L-12)	(TERGITOL 15-S-7)	(TERGITOL 15-S-
1. FOAM QUANTITY	HIGH	LOW TO MODERATE	LOW TO MODERATE	LOW TO MODERATE				
2. EFFECT OF HEAT ON FOAM	NONE	DECREASES		DECREASES				
3. DISCHARGEABLE WITH CURRENT EQUIPMENT	YES	YES	YES	YES	YES	YES	YES	YES
4. TOXICITY i) HUMAN	SKIN-IRRITANT EYE-IRRITANT (SEVERE IN CONC.)	SKIN-NONE EYE-IRRITANT (SEVERE IN CONC.)	SKIN-IRRITANT EYE-IRRITANT (SEVERE IN CONC.)		SKIN-IRRITANT EYE-IRRITANT	SKIN-IRRITANT EYE-IRRITANT		
ii) ANIMAL LD$_{50}$ (MG/KG)[1]	ORAL, RAT-1200 SKIN-IRRITANT (MILD) EYE-IRRITANT (SEVERE)	ORAL, RAT-1900	ORAL, RAT->5000	ORAL, RAT-1310	ORAL, RAT-2.83 EYE-IRRITANT	ORAL, RAT-3.25 EYE-IRRITANT	ORAL, RAT-3.25	ORAL, RAT-3.
5. CORROSION POTENTIAL								
6. COST ($ PER LB. OF CONC. 1970)	0.2	0.40	0.35	0.35	0.40	0.40		

[1] Higher LD$_{50}$ values indicate relatively lower toxicity.

TABLE 3. SECONDARY FOAMS
CRITERIA/EVALUATION

ETHOXYLATED STRAIGHT CHAIN ALCOHOLS				SODIUM LAURYL SULFATE	SOAP-LAURIC ACID, SODIUM SALT	POLYETHYLENE GLYCOLS	
(TERGITOL 15-S-7)	(TERGITOL 15-S-12)	(NEODOL 25-7)	(NEODOL 25-12)	(SIPONATE DS)	(IVORY SNOW)	(POLYOX WSR-N 10)	(PLURONIC P-94)
		MAY FORM GEL (IF ADD LOW AMOUNT OF WATER TO NEODOL)	MAY FORM GEL	HIGH	MODERATE		VERY LOW
					NONE		NONE
YES	YES	YES	YES	YES	YES	YES	YES
		INHAL.-HEADACHE, DIZZINESS, NAUSEA SKIN-IRRITANT EYE-IRRITANT	INHAL.-HEADACHE, DIZZINESS, NAUSEA SKIN-IRRITANT EYE-IRRITANT	SKIN-IRRITANT (MILD) TOXIC VAPORS	EYE-IRRITANT		SKIN-IRRITANT EYE-IRRITANT
ORAL, RAT-3.25	ORAL, RAT-3.38	ORAL, RAT-2700	ORAL, RAT-1800	ORAL, RAT-1288 EYE-IRRITANT (MILD)	MOUSE- LD_{50}: 400 MG/KG (ROUTE UNREPORTED) SKIN (RAT)- IRRITATION (SEVERE)	ORAL, RAT-33750 SKIN-NONE EYE-IRRITATION (MODERATE)	ORAL, RAT- > 15000
				8.03	8.03		

Ultrawet K solution and looked for emissions of sulfuric acid vapors that would be present if sulfur oxides were formed in the solution. Because no acid vapors were detected, we concluded that sulfur oxides were not formed in an appreciable amount under these conditions.

The evaluation of the available information on this surfactant indicated that this foam is compatible with most of the listed criteria. Hence, this product could be a likely surrogate for AFFF.

2.2.1.2.2 Ethoxylated octyl phenol. We evaluated one product that contains ethoxylated octyl phenol—Triton X-100 (Rohm and Haas). This surfactant is readily available commercially (2.9 million pounds were produced in 1979) and is inexpensive ($0.49 per pound in 1979; see Appendix E). Human and animal (mammalian) toxicity data indicate that this surfactant is relatively nontoxic, and that the thermal decomposition products should be nontoxic in the trainer environment.[1] Preliminary tests indicated that Triton X-100 produces a low to moderate quantity of foam that dissipates slightly at high temperatures. The product is nonflammable. There is no information available on the corrosion potential of the foam.

Triton X-100 is biodegradable; however, the foam produced in the effluent is toxic to aquatic life, as is the case with all of the foams. Triton X-100 is toxic to fish (bluegill) at levels of 10 to 12 mg/l. The foam cannot be directly discharged into natural waters, but it can be disposed of into a POTW if it meets the standards of the POTW.

The evaluation of the available data on Triton X-100 indicated that this product meets most of the listed criteria. This product would be a likely substitute for AFFF if the foaming action remains adequate at the high temperatures in the trainer.

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[1] Although the Material Safety Data Sheet describes Triton X-100 as toxic, we recognize that this statement refers to the concentrated surfactant. While all concentrated surfactants are toxic, the foam used in the trainer will be a very dilute solution (less than 0.5 percent) and, therefore will be relatively nontoxic.

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2.2.1.2.3 Ethoxylated nonyl phenol. Two products that we evaluated containing ethoxylated nonyl phenol were Triton N-101 (Rohm and Haas) and Tergitol NP-9, NP-10 (Union Carbide). These products are similar to each other but differ from Triton X-100 since these products are ethoxylated nonyl as opposed to an ethoxylated octyl phenol. At present, the ethoxylated nonyl phenol type of surfactant has a much higher production volume (308 million pounds in 1979) than the ethoxylated octyl phenol type (2.9 million pounds in 1979). In contrast to the greater commercial availability of the ethoxylated nonyl phenol type, there is less data available on these products than on Triton X-100, which has been manufactured and in use for a longer time.

This surfactant is readily available and inexpensive ($0.35 per pound in 1979; see Appendix E). The human and animal (mammalian) toxicity data indicate that these products are relatively nontoxic, and that the thermal decomposition products should also be nontoxic in the trainer environment. Preliminary tests showed that these products form a low to moderate quantity of foam that dissipates slightly at high temperatures. These products are nonflammable. There is no information available on the corrosion potential of the foam.

These products are biodegradable, but the foam is toxic to aquatic life. The Tergitol products are toxic to fish (fathead minnow) at an average concentration of 1.6 to 24 mg/l. The foam cannot be directly discharged into natural waters, but it can be disposed of into a POTW if it meets the POTW standards.

The evaluation indicates that these products meet most of the listed criteria. If the foaming action remains adequate at the high temperatures of the trainer, then these products could be likely surrogates for AFFF.

2.2.1.2.4 Ethoxylated straight-chain alcohols. We evaluated six products that contain ethoxylated straight-chain alcohols:

- Tergitol 25-L-7 (Union Carbide)
- Tergitol 25-L-12 (Union Carbide)
- Tergitol 15-S-7 (Union Carbide)
- Tergitol 15-S-12 (Union Carbide)
- Neodol 25-7 (Shell)
- Neodol 25-12 (Shell).

The production volume of surfactants that include the Tergitol 25-7 series was 567 million pounds in 1979 (see Appendix E). There is no other information available on production volumes for these candidates. The toxicity data indicated that these surfactants may be relatively more toxic than

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the other candidate AFFF substitutes. The toxicity data reported by the manufacturer for the Neodol products indicated that inhalation of these products can cause headache, dizziness, and nausea. The animal toxicity data reported by the manufacturer for the Tergitol products indicated that the oral LD_{50} values in rats were much lower than the values reported for the other candidates. Hence, the Tergitol products may be relatively more toxic than the other candidate foams. The thermal decomposition products of the Neodol and Tergitol products may be acidic in an aqueous environment.

Information supplied by the manufacturer indicated that the Neodol surfactants are flammable. In aqueous solution, they may form a gel under certain conditions. These characteristics are unsuitable to the requirements of the fire fighter trainer. Moreover, the manufacturer specified that the Neodol products could not be discharged into public water systems, but must be incinerated or disposed into landfills. This disposal characteristic is also unsuitable for an AFFF surrogate.

Data supplied by the manufacturer of the Tergitol products indicated that these foams are biodegradable but are toxic to aquatic life. The products were toxic to fish (fathead minnow) at levels of 10, 10, 3.7, and 3.2 mg/l for Tergitol 25-L-7, L-12, S-7 and S-12, respectively. Therefore, as with the other candidate foams, these products cannot be directly discharged into natural waters, but can be discharged into a POTW if they meet the POTW's standards.

There was no information available on the corrosive potential of these foams. We did not obtain information concerning the cost of these products because they did not appear to be the most viable surrogates for AFFF, given their undesirable features of toxicity, flammability, and/or potential to form a gel.

2.2.1.2.5 Sodium lauryl sulfate. One product that we evaluated containing sodium lauryl sulfate was Maprofix 563 (Onyx Chemical Company). The production volume of this surfactant was 20 million pounds, and it cost $0.88 per pound in 1979. Information from the U.S. Navy indicated that this surfactant produces good foaming action (memorandum N-73:RJH, 24 August 1978, "Substitute Foam Agent, Preliminary Study of," and memorandum N-73:ES, 2 October 1978, "Evaluation of Sodium Lauryl Sulfate as a Substitute Foam Agent for Firefighting Training, Request for"); however, the dry powder is flammable and produces an acidic vapor. It has been reported that this compound releases toxic vapors of sulfur oxides during combustion (Sax, N.I., Dangerous Properties of Industrial Materials, 5th ed., 1979, p. 984).

The foam is biodegradable but cannot be directly discharged into natural waters. It may be disposed into POTWs with proper treatment. There is no information available on the corrosion potential of this surfactant or the effect of heat on its foaming action.

2.2.1.2.6 Soap--sodium laurate. We evaluated Ivory Snow (Proctor and Gamble) as one product containing sodium laurate. This surfactant is readily available commercially (production volume was 151 million pounds in 1979) and is inexpensive ($0.48 per pound in 1979). Preliminary tests indicated that the product produces a moderate foaming action that is apparently not affected by heat. The product is nonflammable and biodegradable.

Toxicity data from the manufacturer are necessary to document safety aspects of this surfactant, although its long-term use suggests it is safe. This surfactant might be a possible substitute for AFFF; however, relevant data are unavailable, and the manufacturer is not interested in this use for their product. In addition, extensive testing would be required to evaluate the effectiveness of this product in a fire-fighting environment, as well as its human and environmental safety aspects.

In subsequent tests, we observed that this product was not sufficiently soluble in cold water to produce a foam that would reliably activate the sensors in the trainer. Hence, we eliminated this candidate in a later phase of the evaluation.

2.2.1.2.7 Polyethylene glycols. Two products that we evaluated containing polyethylene glycols were Polyox WSR-N 10 and Pluronic P-94. These products are foam stabilizers and will not produce a foam. Pluronic P-94 is disposable in water effluent only in small amounts. These compounds are not viable substitute foam extinguishing agents but may be considered as potential foam additives if stabilization is necessary.

2.2.1.3 Rank ordering and selection of optimal candidates. We ranked the candidate substitutes for AFFF according to their relative ability to satisfy the evaluation criteria described in the previous section. Following the ranking process, we selected the two highest ranked candidates for further limited laboratory analysis and onsite testing.

2.2.1.3.1 Rank ordering. The ability of each candidate foam to meet the evaluation criteria is summarized in Table 4.

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CRITERIA	SODIUM DODECYL BENZENE SULFONATE (ULTRAWET K. WACCONOL 35 SL)	ETHOXYLATED OCTYL PHENOL (TRITON X-100)	ETHOXYLATED NONYL PHENOLS		ETHOXYLATED		
			(TRITON N-101)	(TERGITOL NP-9 NP-10)	(TERGITOL 25-L-7)	(TERGITOL 25-L-12)	(TERGITOL 15-S-?)
1. PRODUCTION VOLUME	+	+	+	?	+	+	?
2. NONFLAMMABILITY	+	+	+	+	?	?	?
3. ENVIRONMENTAL FACTORS							
i) DISPOSABILITY IN EFFLUENT	+	+	+	+	+	+	+
ii) BIODEGRADABILITY	+	+	+	+	+	+	+
iii) AQUATIC TOXICITY	?	—	?	—	—	—	—
4. THERMAL DECOMPOSITION PRODUCTS	?	+	+	+	+	+	+
5. DETECTABLE BY SENSORS	+	+	?	?	?	?	?
6. FOAM QUANTITY	+	+	?	+	?	?	?
7. EFFECT OF HEAT ON FOAM	+	✶	?	✶	?	?	?
8. DISCHARGEABLE WITH CURRENT EQUIPMENT	+	+	?	?	?	?	?
9. TOXICITY							
HUMAN	+	+	+	?	+	+	?
ANIMAL	+	+	+	+	—	—	—
10. CORROSION POTENTIAL	?	?	?	?	?	?	?
11. COST	+	+	+	+	+	+	?

NOTE: POTENTIAL SUBSTITUTES RANKED FROM LEFT TO RIGHT IN ORDER OF DECREASING DESIRABILITY

KEY: + MEETS CRITERIA
— DOES NOT MEET CRITERIA
± CONDITIONALLY MEETS CRITERIA
? NO DATA/UNCERTAIN DATA
✶ UNDEFINED DISSIPATION OF FOAM WITH HEAT

TABLE 4. FOAMS CRITERIA/SUMMARY OF EVALUATION

ETHOXYLATED STRAIGHT CHAIN ALCOHOLS					SODIUM LAURYL SULFATE	SOAP-LAURIC ACID, SODIUM SALT	POLYETHYLENE GLYCOLS	
(25-L-12)	(TERGITOL 15-S-7)	(TERGITOL 15-S-12)	(NEODOL 25-7)	(NEODOL 25-12)	(SIAPROFIX 98S)	(IVORY SNOW)	(POLYOX WSR-N 10)	(PLURONIC P-84)
	?	?	?	?	+	+	?	?
	?	?	–	–	–	+	?	+
	+	+ –	–	–	+	+	+	–
	+	+	+	+	+	+	+	+
	–	–	?	?	?	?	?	?
	+	+	?	?	–	+	+	+
	?	?	?	?	?	–	?	?
	?	?	–	–	+	+	–	–
	?	?	?	?	?	+	–	–
	?	?	?	?	?	–	?	?
	?	?	–	–	–	+	?	+
	–	–	+	+	+	?	+	+
	?	?	?	?	?	?	?	?
	?	?	?	?	+	+	?	?

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We ranked these foams based on their relative ability to satisfy the following criteria:

- High production volume
- Low cost
- Biodegradability
- Disposability
- Nontoxic heat decomposition products of foam
- Nontoxic foam
- Availability of information on the foam
- Dischargeability of foam with current equipment
- Minimal effect of heat on foaming action
- Detectability of foam with sensors.

The rank order of the candidate foams according to these criteria is summarized in Figure 9. The order of the candidates starting with those that satisfied the most criteria is as follows:

- Sodium dodecyl benzene sulfonate (higher ranked)

  - Ultrawet K (Arco)

- Ethoxylated octyl or nonyl phenols (higher ranked)

  - Triton X-100 (Rohm and Haas)
  - Triton N-101 (Rohm and Haas)
  - Tergitol NP-9 (Union Carbide)
  - Tergitol NP-10 (Union Carbide)

- Soap (higher ranked)

  - Sodium laurate (Ivory Snow, Proctor and Gamble)

- Ethoxylated straight-chain alcohols (lower ranked)

  - Tergitol 25-L and 15-S series (Union Carbide)
  - Neodol 25-7, 25-12 (Shell)

- Sodium lauryl sulfate (lower ranked)

  - Maprofix 563 (Onyx Chemical Company)

- Polyethylene glycols (lower ranked)

  - Polyox WSR-N 10
  - Pluronic P-94.
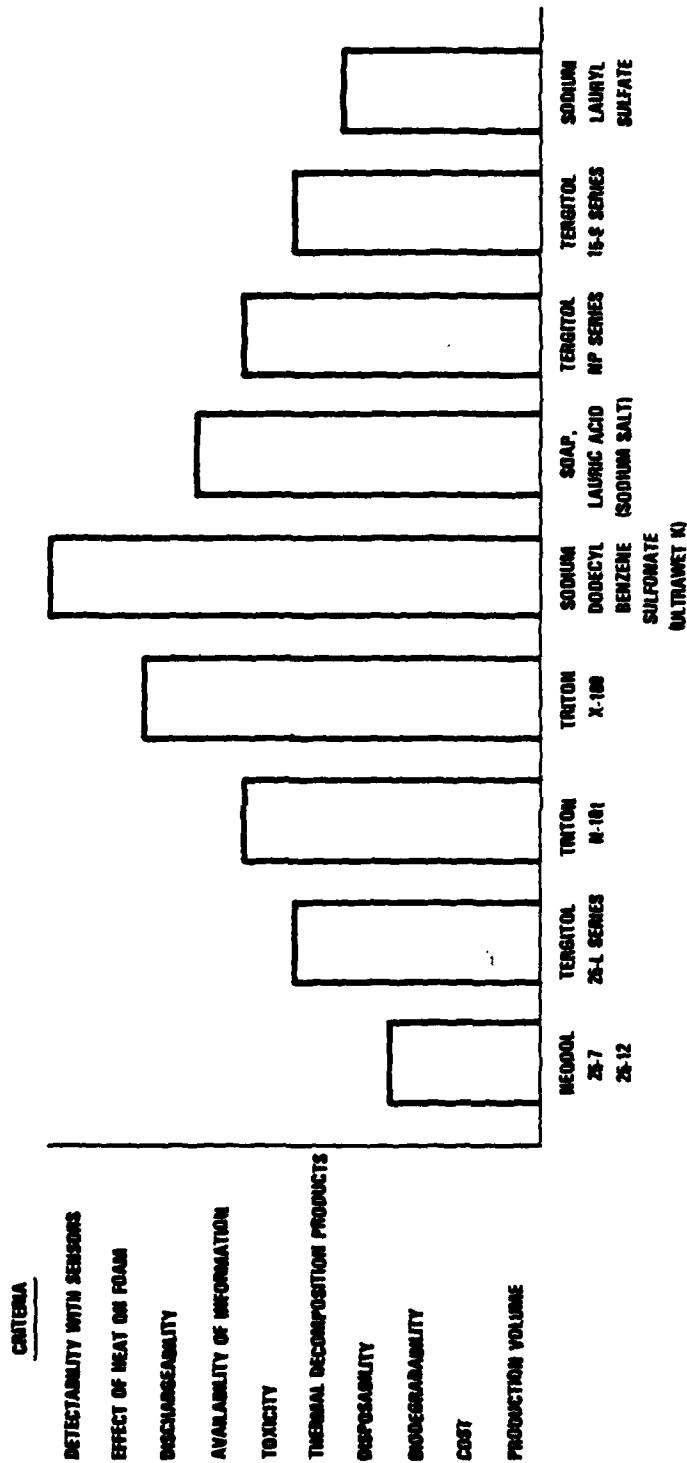
Figure 9. Selection of Optimal AFFF Surrogate Foam

As shown in Figure 9, sodium dodecyl benzene sulfonate (Ultrawet K) is first in the ranking because it meets all of the listed criteria. Triton X-100 is ranked second because it meets all but one of the criteria (e.g., the foaming action dissipates slightly at high temperatures). The third-ranked foam is sodium laurate (Ivory Snow), which we observed through limited testing to be difficult to dissolve in cold water to produce a dischargeable foam. Triton N-101 and the Tergitol NP series products rank below the first three candidates because there was not adequate information available to determine their ability to meet some of the necessary criteria, although they met many of the listed criteria.

The Tergitol 25-L and 15-S series products are lower in the ranking because of their relatively greater toxic potential. Sodium lauryl sulfate also has a low ranking because of potentially toxic thermal decomposition products. The Neodol 25-7 and 25-12 products are lowest in rank because they did not meet our criteria for disposability. We eliminated the polyethylene glycol products from consideration because they do not produce a foam but are only foam stabilizers.

2.2.1.3.2 Selection of optimal candidates. Following the rank ordering of the candidate substitutes for AFFF, we selected the two highest ranked, candidates for further limited laboratory analysis and onsite testing--sodium dodecyl benzene sulfonate and Triton X-100.

2.2.1.3.2.1 Sodium dodecyl benzene sulfonate--Ultrawet K (Arco). This candidate foam has met most of the evaluation and selection criteria for an AFFF surrogate. It is manufactured in very high volumes and is an ingredient in most laundry detergents. Hence, it is readily available and is inexpensive. This candidate produces a high foaming action that is not adversely affected by heat. The foam is relatively non-toxic and is biodegradable. This product has been proposed in the patent literature for use as a fire-fighting extinguishment, and Arco has informed us of such use in 0.1-percent solutions. Because the product is a powder, it requires mixing and formulation. However, a 40-percent liquid concentrate is also available.

2.2.1.3.2.2 Ethoxylated octyl phenol--Triton X-100 (Rohm and Haas). This candidate foam ranks right behind Ultrawet K for meeting most of the evaluation and selection criteria for an AFFF surrogate. This product is readily available and inexpensive, but its production volume is less, and it costs slightly more than Ultrawet K. This product produces a low to moderate foaming action that dissipates slightly at high temperatures. The foam is relatively nontoxic and is biodegradable. This surfactant has been proposed by the Jefferson

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Chemical Company as a fire-fighting foam (Patent No. 3,578,590).
It is a nonflammable liquid that boils away at high temperature.
Because it is a liquid concentrate, it will not require formu-
lation.

2.2.1.4 Laboratory analysis. We subjected the two highest
ranked foam candidates Ultrawet K and Triton X-100 to limited
laboratory analysis to clarify their potential utility as AFFF
surrogates. Each candidate was submitted to a series of tests
that approximated the conditions during use in the fire fighter
trainer.

2.2.1.4.1 Limited laboratory tests. For each of the
selected candidates, we conducted limited laboratory tests to
determine the following:

- Chemical and physical responses to heat of the concen-
  trated surfactant and of the proposed dilution for use
  in the extinguisher

- If the foam dilution proposed for use in the trainer
  would generate products at high temperatures that
  would cause concern regarding health or environmental
  safety, or of corrosion to the equipment

  - Without the presence of a bicarbonate-based dry
    chemical extinguishing agent

  - With the presence of the powder extinguishing
    agent.

2.2.1.4.2 Acidity and residue tests on concentrated sur-
factants. A small amount (0.5 gm) of each material was placed
in a glass tube and heated with a gas flame until the surfac-
tant began to vaporize and give off volatile material. The
generated gases and vapors were led out of the tube and checked
for acidity. The results are tabulated below:

Material	Measured Values	Comments
Ultrawet K	Vapors acidic, pH of 2. When trapped in water, pH essentially neutral 6.5 to 7.	Residual melt was alkaline, pH of 10.
Triton X-100	Vapors neutral to indicator paper and had pH of 7.0 when dissolved in water.	Residue was neutral.

Another small portion of each substance was heated on a metal surface using a gas flame. Each burned with a yellow flame. The Ultrawet K left an appreciable amount of ash; no ash remained from the Triton X-100.

2.2.1.4.3 Acidity and residue tests on foam dilutions. A 5-percent solution of each material was made to represent the concentrates that would be aspirated into the foam nozzle. A portion of this concentrate was then diluted with 16 parts of water to simulate the final concentration applied from the foam nozzle.

Fifty milliliters of this solution were placed in a porcelain crucible and heated to 370°C on a hot plate. The sample progressively boiled off, fumed, and ultimately heated down to a residue. The results are as follows:

Foaming Agent	Observations
Ultrawet K	No acid vapors detected, large volume of black residue formed.
Triton X-100	No acid vapors detected, only a trace of dark brown residue.

The results indicated that neither foam solution generated a detectable level of acid vapors at high temperatures. Hence, the proposed dilution for use of these foams in the trainer should not be associated with adverse effects due to acidity.

2.2.1.4.4 Distillation tests for detection of sulfates, sulfites, and carbonates. One hundred milliliters (ml) of the same foam solutions (i.e., 5-percent concentrated surfactant diluted with 16 parts of water) were placed in a distilling round-bottom flask. The solution was distilled to dryness and charred, and a nitrogen stream swept the flask into a receiver containing distilled water. This operation was performed under three different conditions to simulate the situation without dry chemical agents or with powders present, as follows:

- Without the presence of a bicarbonate-extinguishing agent
- With potassium bicarbonate (Purple K)
- With sodium bicarbonate.

When extinguishing powder was present, 4.8 gm of each were added to the 100 ml of foam solution. This was selected based on a calculated estimate of how much dry chemical would probably be in the foam solution applied. The distillate was checked for presence of sulfates, sulfites, and carbonates.

The results, which are presented in Table 5, indicated that none of the conditions tested produced detectable amounts of sulfates (SO_4), sulfites (SO_3), or carbon dioxide (CO_2). Hence, these results suggested that there should be no adverse effects associated with these types of emissions under these conditions using the specific surfactants and powders tested.

2.2.1.5 Analysis of foams for detectability by sensors. A major operational criterion for an AFFF surrogate is that it produce a foam that activates the sensors in the fire fighter trainer. Two sets of tests were performed on the foam candidates to determine their detectability potential. These tests are discussed in the following sections.

2.2.1.5.1 Preliminary pretest of detectability potential. Preliminary pretests were conducted at ATS to determine the detectability potential of the following three foam candidates, using the dilutions proposed for use in the extinguishers:

- Ultrawet K (5-percent solution x 16 dilution factor)
- Triton X-100 (5-percent solution x 16 dilution factor)
- Ivory Snow.

These foams were subjectively tested for visual evidence of foaming action. Tested Ultrawet K and Triton X-100 dilutions produced good foams that might be detectable by the sensors. Ivory Snow did not foam in the extinguisher, and a 2-percent solution formed a gel. Hence, Ivory Snow was eliminated from further consideration.

2.2.1.5.2 Onsite pretests for functional operation with sensors. Onsite pretests for detectability of the foam candidates by the sensors were performed on Triton X-100 and Ultrawet K. The results of the Triton X-100 tests are as follows:

- Neither 5- nor 10-percent concentration was satisfactory for sensor activation.

- Ten-percent concentration is a slightly better foamer than the 5-percent concentration, but it is still inadequate.

- Dilution requires warm water (cold water causes material to gel and settle out of solution).

TABLE 5. RESULTS OF LIMITED LABORATORY ANALYSIS
OF FOAM CANDIDATES

SAMPLE	AMOUNT	COMMENTS	QUALITATIVE TESTS FOR SO_3, SO_4 AND CO_2
ULTRAWET K AND PYRO-PK	100 ML ULTRAWET K (5% DILUTED X 16) 4.8 GMS PYRO-PK.	HEAVY FOAMING DURING DISTILLATION. DIS-TILLATE HAD A SLIGHT HAZE AND A STRONG, ACRID BURNT ODOR. RESIDUE WAS GRAY/BLUE SOLID.	NEGATIVE
ULTRAWET K AND PYRO-BCS	100 ML ULTRAWET K (5% DILUTED X 16) 4.8 GMS PYRO-BCS.	HEAVY FOAMING DURING DISTILLATION. DIS-TILLATE HAD A SLIGHT HAZE AND A STRONG, ACRID BURNT ODOR. RESIDUE WAS AN OFF WHITE SOLID.	NEGATIVE
TRITON X100 AND PYRO-PK	100 ML TRITON X100 (5% DILUTED X 16) 4.8 GMS PYRO-PK.	LITTLE FOAMING DURING DISTILLATION. DIS-TILLATE WAS HAZY WITH A WEAK BURNT ODOR. RESIDUE WAS A GRAY/WHITE SOLID.	NEGATIVE
TRITON X100 AND PYRO-BCS	100 ML TRITON X100 (5% DILUTED X 16) 4.8 GMS PYRO-BCS.	LITTLE FOAMING DURING DISTILLATION. DIS-TILLATE WAS HAZY WITH A WEAK BURNT ODOR. RESIDUE WAS AN OFF WHITE COLOR.	NEGATIVE

SOURCE: CASE CONSULTING LABORATORIES, INC.

These test results indicate that Triton X-100 does not produce a foam that is adequate for consistently activating the sensors.

The results of the Ultrawet K tests are as follows:

.   Five-percent concentration is a better foamer than either Triton concentration.

.   Five-percent concentration was marginally acceptable in activating five of the eight sensors.

.   Ten-percent concentration was found to be acceptable to activate all sensors in the bilge area.

These results indicate that Ultrawet K produces a foam that is adequate for activating the sensors.

2.2.1.6   Conclusions.   Based on the results of the limited laboratory analysis and tests for detectability by the sensors, it was apparent that Ultrawet K was the best candidate for use as an AFFF surrogate.   Because Triton X-100 did not activate the current sensing equipment, it was eliminated from further consideration as an AFFF substitute during the onsite sampling program.

Because Ultrawet K was the best candidate, it was subjected to further tests during subsequent field trials at the Naval Training Facility.   For all of these tests, the foam dilution was prepared from a 10-percent solution of Ultrawet K that was diluted with 16 parts of water.   The solution was prepared by dissolving 1 gallon of Ultrawet K solid in water and diluting it with water to a total volume of 5 gallons.

The relevant data for this procedure are as follows:

.   5 gallons of Ultrawet K = 640 oz.
.   0.5 gallons = 64 oz.
.   Specific gravity of solid Ultrawet K = 0.5
.   Therefore, 1 gallon of Ultrawet K = 64 oz. by weight.

For a 10-percent solution by weight, use 1 gallon of Ultrawet K solid to a final volume of 5 gallons in water. Ultrawet K is also available as a liquid in a 40 percent concentrate, and thus would require only further dilution to the desired concentration.   This eliminates the need to make a liquid concentrate from the powdered base material; however, the cost of transportation would be significantly higher due to the excess weight of the water.

2.2.2 PKP extinguishment substitute. PKP, the dry powder extinguishing agent currently planned for use in the 19F1, has several undesirable characteristics as was identified in Booz, Allen's Phase I report. These undesirable characteristics included the following:

- Extreme diffusiveness and difficulty to control
- Skin irritation
- Deterioration of painted surfaces
- Corrosiveness to metal surfaces
- Penetration of electronics and controls
- Visible white plume when exhausted from trainer.

Booz, Allen investigated possible substitute powders for use as a PKP surrogate in the fire fighter trainer. The purpose of this initial evaluation was to select the most likely candidate for onsite testing at the Naval training facility in Norfolk, Virginia.

2.2.2.1 Characterization and evaluation criteria. A candidate substitute dry powder material must be a flame suppressant because both the oil bilge and electrical panel fireplaces use sensors that are activated only when the flames are suppressed below a designated line of sight during powder application. Commercially available candidate substitutes were surveyed according to their potential to meet the following criteria:

- Readily available in large quantities
- Nonflammable
- Environmentally acceptable
- Minimal adverse effects on human health and safety
- Minimal corrosiveness
- Minimal diffusiveness
- Dischargeable into fire with currently used equipment
- Detectable by sensors currently in use
- Cost-effective for training.

We surveyed the following 13 powders:

- Sodium bicarbonate
- Potassium bicarbonate
- Monoammonium phosphate
- Diammonium phosphate
- Carbamic powders
- Potassium chloride
- Potassium sulfate
- Calcium carbonate
- Sodium chloride

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- Calcium sulfate
- Barium sulfate
- Dolomite
- Fly ash

The most commonly available commercial candidates generally meeting these criteria are limited to the following:

- Sodium bicarbonate
- Potassium bicarbonate
- Monoammonium phosphate
- Diammonium phosphate.

Information relevant to the criteria was compiled from literature and interviews with manufacturers to evaluate the suitability of each candidate. The most likely candidates were submitted to limited laboratory testing and analysis. Finally, the best candidate was selected for onsite pretesting and eventual use during the onsite sampling program.

2.2.2.2 Evaluation of utility and environmental safety. The suitability of candidate powders was evaluated according to the previously listed criteria. Available data for each candidate in this phase of the evaluation are summarized in Table 6 and described in the following sections.

2.2.2.2.1 Sodium bicarbonate (Church and Dwight, processed by Pyro Chemical Inc.). This powder is commercially available in a wide range of particle sizes and is currently used as a fire extinguishment. The powder is nonflammable and is disposable as an effluent into a treatment facility. Sodium bicarbonate is alkaline and, at a high concentration, can cause toxicity due to skin irritation. In addition, the alkalinity may cause corrosion of the trainer equipment. Sodium bicarbonate is somewhat less corrosive than potassium bicarbonate.

Because the particles may be very diffusive and, hence, may enhance the potential for corrosion, we were interested in evaluating the diffusivity of the various particle sizes. A sodium bicarbonate sample was processed for testing (silicone-coated, fluidizers added); the particle sizes were selected to pass through a 100 mesh but not a 325 mesh. In the diffusivity tests, described in a later section, it was observed that the larger particles settle far more rapidly. Hence, the use of larger particles may decrease the amount of particulate emissions as well as corrosivity.

TABLE 6. POWDERS CRITERIA/EVALUATION

CRITERIA	SODIUM BICARBONATE	POTASSIUM BICARBONATE	MONOAMMONIUM PHOSPHATE	DIAMMONIUM PHOSPHATE
PRIMARY:				
1. PRODUCT AVAILABILITY	YES	YES	YES	YES
2. FLAMMABILITY	NONE	NONE	NONE	NONE
3. ENVIRONMENTAL FACTORS i) DISPOSABILITY	DISPOSABLE WHEN TREATED	DISPOSABLE WHEN TREATED	PHOSPHATE IS CONTROLLED SUBSTANCE KEEP OUT OF SEWAGE SYSTEM	
ii) AQUATIC TOXICITY				TL_m 96, 1000-100 ppm
4. CORROSION POTENTIAL	YES (BASIC pH)	YES (BASIC pH)	YES (ACID pH)	YES (BASIC pH)
5. DIFFUSION POTENTIAL	SIZE DEPENDENT	SIZE DEPENDENT		
SECONDARY:				
1. DISCHARGEABILITY FROM EQUIPMENT	YES	YES	YES	YES
2. DETECTABLE BY SENSORS IN CURRENT USE	YES (IF RELOCATED)	YES		
3. TOXICITY i) HUMAN LD_{50} (MG/KG)	SKIN-IRRITANT (MILD) (IN HIGH CONC.)	SKIN-IRRITANT pH-8.3		
ii) ANIMAL LD_{50} (MG/KG)	ORAL, RAT-4220	(POT. CARBONATE) ORAL, RAT-1870		

In subsequent tests, the sodium bicarbonate powder was observed to be dischargeable with currently used equipment. Although sodium bicarbonate is less efficient at suppressing flames than potassium bicarbonate, the tests indicated that the sensors are activated during the application of sodium bicarbonate. The only detection problems observed were with the cloud opacity sensor in the deep fat fryer. Section 5.7 addresses this concern.

2.2.2.2.2 Potassium bicarbonate (Mallinckrodt, Dynamit Nobel, processed by Pyro Chem. Inc.). This powder (PKP) is commercially available in large quantities in the standard (fine) particle size but not in coarse particle sizes, and is used as a fire extinguishment. Potassium bicarbonate is nonflammable and is disposable as an effluent into a treatment facility. Potassium bicarbonate is alkaline and at high concentrations can cause skin irritation similar to sodium bicarbonate. The alkalinity will also cause corrosion of the trainer equipment. Potassium bicarbonate may be potentially more corrosive than sodium bicarbonate due to the greater electrical conductivity properties of potassium bicarbonate. Potassium bicarbonate may also be relatively more toxic than sodium bicarbonate as indicated by the lower oral LD_{50} value in rats for potassium bicarbonate (see Table 6).

As with sodium bicarbonate, we conducted tests on the diffusivity of various particle sizes of potassium bicarbonate. A custom sample of PKP was processed for testing (siliconecoated, fluidizers added), having a particle size range selected to pass through a 100 mesh but not a 325 mesh. In the diffusivity tests described in a later section, the larger particles were observed to be less diffusive. Hence, use of the larger particles might result in less corrosion and particulate emissions.

Potassium bicarbonate is the currently used fire extinguishment and, as such, it would be expected that the larger particles would also be dischargeable with currently used equipment. It is more efficient than sodium bicarbonate at suppressing the flames to more easily activate the sensors.

2.2.2.2.3 Monoammonium phosphate. Monoammonium phosphate is widely used as a fire-fighting extinguishment. It is known as ABC powder because it is effective against all A, B, and C classes of fires. This powder is readily available commercially. It is nonflammable and is probably dischargeable by currently used equipment.

There are some major disadvantages to the use of this powder as a PKP substitute in the fire fighter trainer. This powder contains phosphate, which is environmentally controlled and cannot be readily disposed of into sewage systems. In addition, this powder is very acidic (pH of 4.2) in aqueous solutions and can cause corrosion to metals and dermal toxicity to exposed fire fighters.

2.2.2.2.4 Diammonium phosphate. Diammonium phosphate is used as a fire extinguishment but is not as widely used for this purpose as is monoammonium phosphate. The diammonium phosphate powder is nonflammable and probably dischargeable with currently used equipment. The aqueous solution is alkaline (pH of 8) and has a potential at high concentrations to cause corrosion of the equipment and dermal toxicity to the exposed fire fighter.

There is a major disadvantage to the use of this powder as a PKP substitute. Similar to monoammonium phosphate, this powder contains phosphate, which is environmentally controlled and cannot be disposed of into the sewage system. The aquatic toxicity of this powder is very high. The median toxic level to fish (TL_m 96) following a 96-hour exposure occurs in the range of 100 to 1,000 ppm of diammonium phosphate.

2.2.2.3 Rank ordering and selection of optimal candidate. We ranked the candidate surrogates for PKP according to their relative ability to satisfy the criteria previously described. Following the ranking process, we selected the highest ranking candidate for further limited laboratory analysis and onsite testing.

2.2.2.3.1 Rank ordering. The ability of each candidate powder to meet the evaluation criteria is summarized in Table 7.These powders were ranked according to their relative ability to satisfy the following criteria:

- Product availability
- Nonflammability
- Dischargeability
- Disposability
- Detectability with sensors
- Minimized diffusivity
- Minimized corrosion potential
- Relatively less toxicity.

The rank order of the candidate foams according to these criteria is presented in Figure 10. We have subclassified the sodium bicarbonate and potassium bicarbonate powders according

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TABLE 7. POWDERS CRITERIA/SUMMARY OF EVALUATION

CRITERIA	SODIUM BICARBONATE	POTASSIUM BICARBONATE	MONOAMMONIUM PHOSPHATE	DIAMMONIUM PHOSPHATE
1. PRODUCT AVAILABILITY	+	+	+	+
2. NONFLAMMABILITY	+	+	+	+
3. ENVIRONMENTAL FACTORS i) DISPOSABILITY	+	+	-	-
ii) AQUATIC TOXICITY	?	?	?	-
4. CORROSION POTENTIAL	-	-	-	-
5. DIFFUSION POTENTIAL	*	*	?	?
6. DISCHARGEABILITY FROM EQUIPMENT	+	+	+	+
7. DETECTABLE BY SENSORS	+	+	?	?
8. TOXICITY i) HUMAN	-	-	?	?
ii) ANIMAL	-	-	?	?

NOTE: POTENTIAL SUBSTITUTES RANKED FROM LEFT TO RIGHT IN ORDER OF DECREASING DESIRABILITY

KEY:
+ MEETS CRITERIA
- DOES NOT MEET CRITERIA
± CONDITIONALLY MEETS CRITERIA
? NO DATA/UNCERTAIN DATA
* SIZE DEPENDENT
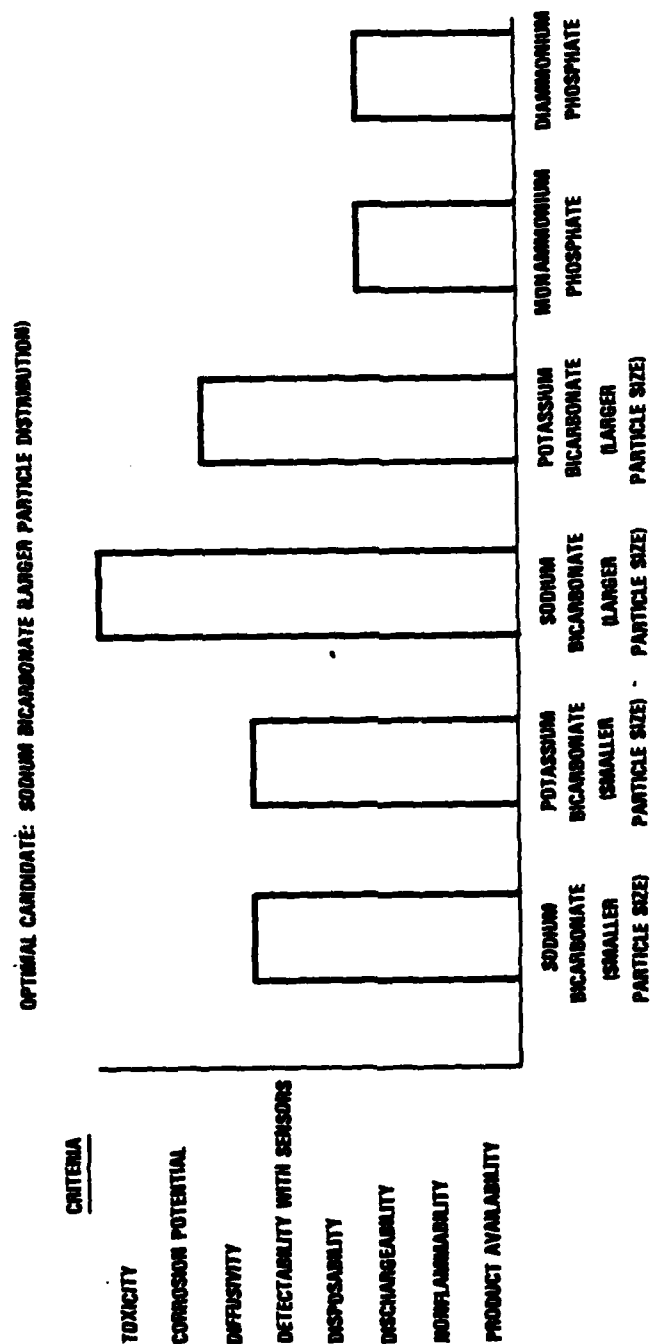
Figure 10. Selection of Optimal PKP Surrogate Powder

to smaller (standard) particle size (approximately 20 to 25 microns) and larger particle size (e.g., passes a 100 mesh but not a 325 mesh). The order of the candidates starting with those that satisfied the most criteria follows:

- Sodium bicarbonate (larger particle size) - higher ranked

- Potassium bicarbonate (larger particle size) - higher ranked

- Sodium bicarbonate (smaller particle size) - higher ranked

- Potassium bicarbonate (smaller particle size) - higher ranked

- Ammonium phosphate - lower ranked

- Diammonium phosphate - lower ranked.

As shown in Figure 10, sodium bicarbonate (larger particle size) is first in the ranking because it best meets all of the listed criteria. Potassium bicarbonate (larger particle size) is next because it met all but two of the criteria (e.g., it is relatively more toxic and corrosive). The smaller sized particles of these powders ranked lower because of their increased diffusivity. The monoammonium and diammonium phosphate powders ranked lowest because they are not disposable into sewage systems. We eliminated the monoammonium and diammonium phosphate powders from further consideration because they do not meet the disposability criteria needed for a PKP substitute.

2.2.2.3.2 Selection of optimal candidate. Following the rank ordering of the candidate powders, we selected the highest ranked candidate, sodium bicarbonate with the larger particle-size distribution, for further laboratory analysis and onsite testing. We also performed some additional tests on the second ranked candidate, potassium bicarbonate with the larger particle-size distribution. These two candidate powders are discussed in the following sections.

2.2.2.3.2.1 Sodium bicarbonate (larger particle size). This candidate powder is available commercially in a wide variety of particle sizes. The larger size particles may be less diffusive than the fine particles (standard size) currently used in fire extinguishers. Pyro Chem Inc. processed sodium bicarbonate into a free-flowing powder of larger particle size

that was suitable for use in fire extinguishers. We tested
this powder for decreased diffusivity, which would indicate a
decreased potential to penetrate and corrode electronics, con-
trols, metal, and painted surfaces in the fire fighter trainer.

Sodium bicarbonate met most of the other criteria for a PKP
substitute. The powder is nonflammable, dischargeable by cur-
rent equipment, and disposable. In our subsequent analysis, we
tested the ability of this powder to decrease the flame suffi-
ciently to activate the sensors in the trainer.

2.2.2.3.2.2 Potassium bicarbonate. Potassium bicarbonate
(PKP) powder, which is currently used in the trainer, is
extremely fine and diffusive. It is not commercially available
in larger particle sizes that might be less diffusive and,
hence, less corrosive. Pyro Chem Inc. prepared small quanti-
ties of powder consisting of larger particles by selectively
screening the conventional powder. This limited sample was
used in our preliminary tests.

2.2.2.4 Laboratory analysis. We selected the highest
ranked candidate powder, sodium bicarbonate, for limited
laboratory analysis to clarify its potential use as a PKP
surrogate. In these tests, we used a standard powder of fine
particle size and a custom preparation of coarser particles.
We included standard and coarser grade samples of potassium
bicarbonate in certain tests for comparison with sodium bicar-
bonate.

We conducted a photographic sequence analysis of the
settling characteristics of the powder samples to elucidate the
effect of particle size on diffusivity. The powder samples
included in these tests were the following:

- Sodium bicarbonate, standard powder
- Sodium bicarbonate, coarse powder
- Potassium bicarbonate, standard powder
- Potassium bicarbonate, coarse powder.

The standard grade of both sodium and potassium bicarbonate
powders consists of fine particles with an average diameter of
20 to 25 microns. We obtained a coarser grade of each powder
from Pyro Chem Inc., which selectively screened particle sizes
that were retained on a 325 mesh (diameter exceeds 44 microns)
but passes through a 100 mesh (diameter is less than 149
microns).

Each powder sample was loaded into an extinguisher. We sprayed a burst of powder from each extinguisher and, by photographic sequence analysis, we monitored the time for dissipation (settling) of the cloud of powder. We observed that the coarse particle samples settled about three times faster than the standard (fine) particle samples. This result indicated that a coarse powder is less diffusive and, hence, may cause less problems with corrosion and interference with equipment.

2.2.2.5 Onsite pretests for functional operation with sensors. Onsite pretests for activation of the sensors by the candidate PKP substitute were performed using sodium bicarbonate, standard powder; and sodium bicarbonate, coarse powder.

For these tests we obtained a commercially available coarse powder (No. 2 grade, from Church and Dwight) that most closely resembled the coarse powder prepared by Pyro Chem Inc. for the limited laboratory analysis. Pyro Chem Inc. processed the No. 2 grade powder by adding fluidizers and silicone coating as follows:

Components	Weight/Percent
Sodium bicarbonate (Church and Dwight, No. 2 grade)	93.4
Attaclay (Engelhard)	4.0
Mica (English Mica Company)	2.0
Silicone fluid (Dow Corning)	0.6
	100.0

The dry components were blended in a Lodige mixer prior to the addition of the silicone fluid. The entire blend was then mixed for 30 minutes, sampled, and loaded into a drum and sealed. Preliminary laboratory analysis indicated the following data on the particle-size distribution of the formulation (three batches that were combined in the delivered drum):

Particle Size Distribution		Church & Dwight Sodium Bicarbonate				Pilot Plant Product		Pyro-BCS
		Bag 1	Bag 2	Bag 3	1	2	3	RAS-67
% retained on 40 mesh		trace	trace	0	trace	0	0	0
	100 mesh	3.2	2.8	3.2	1.0	1.2	1.2	0.2
	140 mesh	35.7	36.0	36.5	29.9	28.2	29.1	0.6
	200 mesh	40.2	40.4	40.4	40.4	38.9	40.0	2.8
	325 mesh	13.9	14.3	13.7	18.5*	23.0*	20.1*	6.7
	Pan	7.0	6.4	6.2	10.2	8.7	9.6	89.7
Apparent Density	g/cm^3	1.04	1.06	1.06	1.11	1.12	1.14	0.971

* Blinded screen.

The data indicate that the formulated coarse grade of powder consisted of particle sizes mainly in the range that were retained on a 325 mesh (44 microns) but passed through a 100 mesh (149 microns). This particle size range is similar to the custom sample prepared by Pyro Chem Inc. for the limited laboratory tests.

The standard and coarse grade sodium bicarbonate powders were tested onsite to clarify their ability to activate the sensors. We observed that both samples activated the sensors in the oil bilge, which detected suppression of the flame height. The course grade of sodium bicarbonate was also observed to be less diffusive than the standard grade. The standard sodium bicarbonate powder behaved virtually identically to standard PKP. Hence, the sodium bicarbonate grade No. 2 (i.e., the coarse powder) activates the sensors and is less diffusive than standard sodium bicarbonate or potassium bicarbonate powders.

In contrast to the sensors in the oil bilge, the PKP sensor in the deep fat fryer is activated by the extinguishment cloud density. During the onsite pretests, the sodium bicarbonate powders inconsistently activated this sensor, although this sensor operated with accuracy during the onsite sampling program. Booz, Allen suggests that consideration be given to replacing this sensor with one that can detect the clearly defined sodium lines produced when the sodium bicarbonate mixes with the open flame. This modification would appear to produce a more reliable sensing mechanism for the sodium bicarbonate powder.

2.2.2.6 Conclusion. Based on the results of the limited laboratory analysis and onsite pretests, it was apparent that the coarse grade No. 2 sodium bicarbonate powder was the prime candidate for use as a PKP surrogate. The grade No. 2 sodium bicarbonate powder is commercially available and detectable by the currently used sensors. It is less diffusive (and potentially less corrosive) than the standard sodium bicarbonate or potassium bicarbonate powders. A coarse grade of potassium bicarbonate powder is not available commercially. It is potentially more corrosive and relatively more toxic than the sodium bicarbonate powder.

To summarize, the grade No. 2 sodium bicarbonate powder appears to be the best candidate for use in the AFFT. This powder was subjected to further tests during the subsequent field trials at the Naval training facility during the onsite sampling program.

2.2.3 Smoke simulants. Dense smoke is a major parameter in effective fire fighter training. The original material proposed for use in the 19F1 AFFT to simulate smoke was propylene glycol.

The undesirable characteristics of propylene glycol (i.e., potential explosiveness, uncontrolled flammability, and generation of toxic thermal decomposition products) identified in Phase I led Booz, Allen to recommend that its use not be continued and that an alternative means of visual obscuration be found. This recommendation was based on research done by the Naval Research Laboratory, the Union Carbide Company,[1] and the Smith and Wesson Company.[1]

During this assignment, Booz, Allen conducted an investigation of the alternative simulated smoke candidates, including a diluted propylene glycol, screened those candidates, and recommended triarylphosphate as the optimum candidate for onsite testing. Salient characteristics for each of the alternative simulated smoke candidates studied are summarized in Table 8.

2.2.3.1 Criteria. To properly evaluate each substitute simulated smoke candidate, Booz, Allen developed a set of criteria for a training smoke with the assistance of ATS and the Naval Training Equipment Center. These characteristics included the following:

- Nonflammability
- Dense visual obscuration
- Mechanical capability for controlled release
- Environmental compatibility and disposability
- Low toxicity on decomposition.

A number of substitute candidates were identified for possible use in the 19F1 AFFT. These candidates fall into the following major classes of smokes:

- Vaporization/condensation

    - Polyethylene glycol (PEG-200)
    - Mineral-based oil ("Pepper Fog")
    - Fatty alcohols
    - Propylene glycol
    - Propylene glycol and 10 percent water
    - Carbon dioxide and warm water

- Chemical

    - Stannic chloride
    - Ethylenediamine and acetic acid
    - Naval tactical FM smoke
    - Triarylphosphate (Chem Chex 220)

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[1] Unpublished research.

CRITERIA	VAPORIZATION/CONDENSATION						CHEMI	
	PEG-200	MINERAL BASED OIL (PEPPER FOG)	FATTY ALCOHOLS	PROPYLENE GLYCOL	PROPYLENE GLYCOL AND 10% WATER	CO_2 AND WARM WATER	STANNIC CHLORIDE	ETHYLENEDIAMINE AND ACETIC ACID
1. RELATIVE FLAMMABILITY POTENTIAL (FLASHPOINT °F)	MODERATE (>340°)	LOW (>400°)	MODERATE (—)	MODERATE (210°)	MODERATE (>210°F)	LOW (—)	LOW (—)	HIGH (110°)
2. RESIDUES	YES (LOW)	YES (MODERATE)	NO	YES (LOW)	YES (LOW)	NO	NO	NO
3. EASILY CONTROLLABLE RELEASE	YES	YES	YES	YES	YES	YES (MODERATE)	NO	NO
4. VAPORIZATION AT <200°F / VAPORIZATION >400°F	NO / POSSIBLY	NO / NO	YES / YES	YES / YES	POSSIBLY / YES	YES / YES	— / —	— / —
5. SMOKE INTENSITY	HIGH	HIGH	MODERATE TO HIGH	HIGH	HIGH	MODERATE TO HIGH	LOW TO MODERATE	LOW TO MODERATE
6. ENVIRONMENTAL COMPATIBILITY AND DISPOSABILITY { WASTE WATER / AIR DISSIPATION }	GOOD / RAPID	MODERATE MAY REQUIRE DETERGENT WASHDOWN / MODERATE	EXCELLENT / RAPID	GOOD / RAPID	GOOD / RAPID	EXCELLENT / RAPID	MODERATE CONTROL Sn / RAPID	MODERATE CONTROL pH / RAPID
7. TOXICITY RESPIRATOR REQUIRED / EYE/SKIN IRRITANT	YES / NO	YES / POSSIBLY	YES / POSSIBLY	YES / NO	YES / NO	POSSIBLY / NO	YES / YES	YES / YES
8. DIFFERENT SMOKE GENERATING EQUIPMENT REQUIRED	YES	YES	NO	NO	NO	YES	YES	YES
9. NOISE WHEN OPERATING	NO	YES (INTENSE)	NO	NO	NO	YES (LOW)	NO	NO
10. POTENTIALLY TOXIC DECOMPOSITION PRODUCTS	YES	YES	POSSIBLY	YES	YES	NO	YES (INCL SnOCL)	YES (ETHYLENE-DIAMINE ACETATE)

TABLE 8.   SIMULATED SMOKES
CRITERIA/EVALUATION

	CHEMICAL				CHEMICAL PARTICULATE	PYROTECHNIC PARTICULATES		
	STANNIC CHLORIDE	ETHYLENEDIAMINE AND ACETIC ACID	NAVAL TACTICAL FM SMOKE	TRIARYLPHOSPHATE (CHEM CHEX 220)	ZnCl$_2$	ACROWAX B	WOOD CHIPS	OIL COMBUSTION
	LOW (—)	HIGH (110°)	HIGH (—)	LOW (>480°F)	LOW (—)	LOW (—)	LOW (—)	— (—)
	NO	NO	YES	YES (MODERATE)	YES (LOW)	NO	NO	YES (HIGH)
	NO	NO	NO	YES	NO	NO	YES MODERATE	YES MODERATE
	— —	— —	— —	NO NO	NO POSSIBLY	NO NO	NO NO	NO NO
	LOW TO MODERATE	LOW TO MODERATE	HIGH	HIGH	HIGH	HIGH	LOW	HIGH
	MODERATE CONTROL Sn RAPID	MODERATE CONTROL pH RAPID	— SLOWLY	6000 RAPID	SLOWLY	SLOWLY	MODERATE	SLOWLY
	YES YES	YES YES	YES —	YES POSSIBLY	YES YES	YES NO	YES NO	YES
	YES	YES	YES	YES	YES	YES	YES	YES
	NO	NO	YES	YES	NO		YES (LOW)	YES (MODERATE)
	YES (HCL SnOCL)	YES (ETHYLENE-DIAMINE ACETATE)	YES	—	POSSIBLY (ZnO)	—	YES	YES

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- Chemical particulate

  - Zinc chloride

- Pyrotechnic particulates

  - Acrowax B
  - Wood chips
  - Oil combustion.

Information used in evaluating the candidates was compiled from the available published and unpublished technical literature, interviews with product manufacturers and researchers (industry and government), and Department of Defense staff. These sources have been summarized in Appendixes B and F. Although additional smokes may be available, those evaluated were considered the most viable for possible use in the 19F1 AFFT.

2.2.3.2 Evaluation. Each candidate smoke was evaluated based on the available information compiled and then compared with other candidates for overall performance in meeting the set of criteria. A brief discussion of each candidate smoke follows.

2.2.3.2.1 Polyethylene glycol. The low molecular weight form of the polymer of ethylene oxide polyethylene glycol (PEG-200) has been proposed as a possible material for use as a training smoke. PEG-200 is a widely used material in a diversity of applications including cosmetics, foods, pharmaceuticals, and textiles.

PEG-200 is a clear viscous liquid at room temperature. It is characterized by a number of ether linkages and by two terminal hydroxyl groups and is less hydroscopic than simple glycols. The material dissolves in water and will not hydrolyze or deteriorate under typical conditions. These properties are attractive for its possible use in the fire fighter trainer.

PEG-200 is being closely evaluated for its use as a field training smoke by the U.S. Army at the Aberdeen Proving Grounds. Although preliminary results of inhalation toxicity studies have been favorable, this research will continue.

The physical properties of PEG-200 include a flash point of more than 340°F, with decomposition occurring prior to boiling. For this reason, the Army conducted its tests using the XM-49 hot air smoke generator rather than a boiler (TMI) unit. The material thermally decomposes to emit both carbon monoxide

and carbon dioxide. Although the material is only moderately flammable, the flammable limits in air are based on tetraethylene glycol, which has a lower flammable limit of 0.9 percent (9,000 ppm). This measurement can be compared with propylene glycol having a lower flammable limit of 2.6 percent (26,000 ppm). Data on the amount of tetraethylene glycol pre- sent in PEG-200 are not available.

PEG-200 can be used to generate a dense smoke. It can be easily controlled for command release, possibly requiring heated piping to reduce premature condensation. Relatively small amounts of residue can be expected to remain within the training facility with its use due to its solubility in water.

PEG-200 appears to be compatible with the environment. It is disposable in wastewater and dissipates rapidly in the air. The smoke generated by this material may vaporize above 400°F, which may be a factor in its use in the 19F1 AFFT. The thermal decomposition products may necessitate the use of a respirator in the trainer, although the material itself is not very toxic. The available data indicate that PEG-200 may be a viable smoke simulant for use in the relatively near future once additional investigations have been conducted.

2.2.3.2.2 Mineral-based oil ("Pepper Fog"). Pepper Fog is a registered trade name for the inert fogging agent sold by the Smith and Wesson Company of Smithfield, Massachusetts. Pepper Fog is a mineral-based oil used in a portable tear gas generating unit. This material, in combination with the generator unit, is currently being used by several fire departments to generate smoke for training exercises. The manufacturer claims that the particle size may vary from <0.1 to 50 μm, producing a variance from a wet to dry fog, based on the equipment setting. The manufacturer has conducted a number of tests showing that the material will remain in 1,000°F atmospheres for about 1 minute before drying out. They also recommend that ventilation be used continuously during its use.

This material has a flash point greater than 400°F and thus has a relatively low flammability rate. This product is expected to leave a moderate amount of residue within the training facility, especially over an extended period of use. Although the release of the smoke is easily controlled using a triggering device on the hand-held smoke generator, it is not readily adaptable for extensive mechanical piping into specific areas of the fire fighter trainer. The smoke generated is dense and is not expected to vaporize, even at high temperatures. The dissipation of the material is moderate in the air.

Because of the residues expected, a detergent washdown of the facility may be required and would then be included in the facility's overall wastewater effluent. A respirator may be required by both the operator of the smoke-generating unit as well as by the individuals in the training facility. Although the smoke may possibly be an eye and skin irritant, it is not considered highly toxic. The smoke generator uses a pulse jet design, causing normal operation to be extremely noisy. This may interfere with training exercises. As with other mineral-based oils, thermal decompositon products are potentially toxic.

2.2.3.2.3 Fatty alcohols. The Chemical Systems Laboratory of the Department of the Army at the Aberdeen Proving Grounds conducted a series of tests under its water fog project. The project involved assessing the use of various fatty alcohols as training smokes. Initially, the emphasis was on using hexadecanol (cetyl alcohol) as a coating material because it spreads spontaneously over small water droplets. However, as the investigation progressed, it was observed that under many atmospheric conditions, hexadecanol did not retard evaporation enough for screening purposes. Additional limited experimental studies have been conducted using a mixture of eicosanol (arachic alcohol) and tetradecanol (myristic alcohol). This fatty alcohol mixture appears to retard evaporation more than hexadecanol.

The specific advantages of the water fog smoke are the ready availability of water, environmental compatibility, and relatively low toxicity. The material is considered only moderately flammable and is not expected to leave a residue with its use. The smoke can be generated using a standard boiler smoke-generating unit and can be easily controlled for demand release. Because of its low vaporization temperature, however, the alcohols would not appear as a visible smoke at temperatures greater than about 200°F. A respirator may still be required for its use in dense atmospheres as toxic thermal decomposition products may be produced. The water fogs are primarily used in field applications and not in hot environments. Vaporization problems have been observed during field trials on hot summer days.

2.2.3.2.4 Propylene glycol. Propylene glycol is a relatively innocuous material. Its inherent low toxicity has made it a prime candidate as a relatively nontoxic training smoke, and it has been proposed for use in the 19F1 AFFT by the Naval Training Equipment Center.

Propylene glycol is moderately flammable, with a flash point of 210°F. Its release can be easily controlled and directed with the use of heated pipes to remote areas of the fire fighter trainer. It is expected to leave few or no residues even after long periods of use. The propylene glycol fog will vaporize at a temperature of approximately 145°F; therefore, most of the material will be a vapor rather than a condensate when used in the fire fighter trainer. Although an intense smoke can be generated, it may not remain in that dense visually obscuring condition. Propylene glycol is environmentally compatible and easily disposable in wastewater and will dissipate rapidly in the air. A respirator may be required with its use in the fire fighter trainer. This assumption is based on studies conducted by the Naval Research Laboratories identifying thermal decomposition products.

Based on our compilation of available data and on extensive work conducted by the Naval Research Laboratories on propylene glycol fog, we advised ATS that propylene glycol fog should not be used simultaneously with fireplace operation due to a significant potential for layering of the propylene glycol and subsequent ignition. We further recommended that extreme caution be exerted in any testing where both propylene glycol fog and open flames are involved. As part of this assignment, Booz, Allen considered the alternative use of a diluted propylene glycol material for its potential use as a training fog.

2.2.3.2.5 Propylene glycol and 10-percent water. A limited assessment was made for the possible use of a diluted propylene glycol solution (9:1 with water) as a training smoke. The diluted propylene glycol solution has primarily the same characteristics as the concentrated propylene glycol material. Based on an interview with Union Carbide, a manufacturer of propylene glycol, it was ascertained that the flash point of the solution would be higher than that for the concentrated material (210°F). Although this diluted material has not been tested in a high-temperature environment, the material as a condensate fog is still expected to vaporize at less than 200°F. Therefore, although the flammability potential would be reduced, the usual training effectiveness would still be questionable.

2.2.3.2.6 Carbon dioxide and warm water. The use of a theatrical smoke is an optimal candidate for use as a training tool. Large volumes of heavy white smoke can be created by mixing carbon dioxide as a solid (i.e., dry ice) with warm water. This material is relatively nonflammable and will not leave any residue, even after prolonged use. The smoke can be easily controlled for demand release and directed by a venting

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system to remote areas of the trainer. The environmental compatibility for carbon dioxide would be excellent with rapid dissipation in the air. The relative toxicity of the material is extremely low, although a respirator could be required. A different type of generating equipment other than that currently proposed would be required. With the possible exception of asphyxiation from the carbon dioxide itself, no thermal composition products would be expected to present a potential health hazard.

The major flaw in the use of this apparently ideal product would be the behavior of the smoke in the heated environment. Carbon dioxide will vaporize well under 200°F; therefore, its use in a real fire situation cannot be considered as an effective training tool.

2.2.3.2.7 Stannic chloride. Stannic chloride is used in ventilation smoke tubes for estimating the velocity of slow-moving ventilating currents by timing the travel of the smoke emitted from the tube once air has been aspirated through it. Upon contact with the moisture in the air, stannic chloride hydrolyzes and forms hydrochloric acid and stannic oxichloride. This reaction releases a visible smoke that consists of stannic chloride and hydrogen chloride. Both materials are controlled substances with respective threshold limit values of 2 mg/m^3 (as tin) and five parts per million (ceiling). Physical contact with the corrosive acid chemical will cause burns, and inhaling the smoke may cause irritation of the upper respiratory tract. The spent material must be handled as a strong acid when disposed of. In addition, ventilation is required when the material is deactivated.

Although this material produces a low to moderately dense smoke, is relatively nonflammable, and does not leave a residue, its release is extremely difficult to control once it is activated with air. In addition, it is only moderately compatible with the environment as it would require the removal of the tin content as well as neutralization of the acid. The material is considered highly toxic and forms potentially toxic thermal decomposition products. Extreme caution must be exercised with its use, and sufficient ventilation must be provided to prevent accumulation of fumes. In addition, careful handling as well as maintaining the materials in closed containers would be required.

2.2.3.2.8 Ethylenediamine and acetic acid. This material is used in a more up-to-date version of the original smoke tube kit that uses stannic chloride. The ethylenediamine reacts with acetic acid, forming ethylenediamine acetate in the form

of a smoke. The specific threshold limit values for both ethylenediamine and glacial acetic acid are 10 parts per million. Although ethylenediamine acetate has no specific threshold limit value, physical contact with the chemicals in the tubes will cause burns, and breathing the smoke may irritate the upper respiratory tract. This material should be handled as a strong acid when disposed of, and ventilation is required while deactivating.

The general characteristics of this smoke are similar to those of stannic chloride, except that this smoke has a considerably lower flash point. The use of this particular smoke would approximate the effectiveness of the stannic chloride with the exception of slighly more control over the directed release of the smoke on command.

2.2.3.2.9 Naval tactical FM smoke. An extremely limited amount of information was obtained concerning this particular candidate. This material has been used by the Navy as a tactical smoke. It is not readily controllable for demand release and leaves a residue. It generates an intense smoke and dissipates slowly in the air. A respirator would probably be required for its use as well as smoke-generating equipment different from that currently proposed. Because a civilian flashback accident in a fire fighter training situation using this smoke was recently reported, its continued use for this application is questionable.

2.2.3.2.10 Triarylphosphate (Chem Chex 220). Chem Chex 220 is the trade name for a butylated triphenylphosphate material. This proprietary material is sold by Tifa Ltd. of Milburn, New Jersey, for conjunctive use with its smoke-generating equipment. Typical applications of this equipment are for generating smoke in power plant stations for leak detection and for generating aerosol fogs (mixed with insecticides) for insect/pest control. Specific data on both the material and the generating equipment are included in Appendix D. A similar triarylphosphate material is commonly used as a hydraulic fluid on aircraft carriers; however, the specific chemical identity of these fluids are not public knowledge.

A recent study by the David W. Taylor Naval Ship Research and Development Center evaluated the outgassing of triarylphosphate in various experimentally heated conditions. Only under temperature conditions greater than 250°C were any quantities of emissions observed. These emissions were of extremely low resultant concentrations (versus kilogram quantities) and included carbon monoxide, aldehydes, and nitrogen dioxide.

Triarylphosphate (Chem Chex 220) is a prime candidate for use as a training smoke. It has a relatively low toxicity, although a respirator is still recommended with its use. The material is considered relatively nonflammable with a flash point of over 400°F and does not vaporize at temperatures greater than 400°F. It can be relatively easily controlled for demand release and directed into remote quadrants of the fire fighter trainer. The material appears to be environmentally compatible, being both disposable in wastewater effluent and rapidly dissipated in the air.

Prolonged use of this fogging material may result in a moderate residue, even though the foaming agents may have a detergent effect. In addition, some eye irritation may occur with its use. With the exception of the David W. Taylor Naval Ship Research and Development Center study and a very recent study by the manufacturer, there are no additional data on thermal decomposition products. Triarylphosphate (Chem Chex 220) is currently used in fire fighter training exercises in Europe (both indoors and outdoors).

2.2.3.2.11 Zinc chloride. Zinc chloride has been used for many years in the generation of large quantities of a light gray smoke used for both training exercises and for various commercial applications. The smoke generators are basically a smoke bomb-type of equipment. After they are ignited or chemically activated, the generators continue to produce smoke for a designated period of time. They do not permit easily controlled demand release after ignition.

These smoke products have been used extensively by U.S. fire departments for training for more than 25 years. The smoke is considered relatively harmless by the manufacturer and was developed mainly for familiarizing trainees with the problems and hazards of working in dense smoke while wearing respirators. Improper mask use will result in eye irritation. The manufacturer of this material believes that in many fire fighter training situations, excessive amounts of smoke are used rather than blending the smoke with ventilation to provide the desired obscurity.

The smoke is not a true smoke but a zinc chloride mist with a high-moisture content and some natural products of combustion, such as free carbon. Because a large portion of the smoke is moisture condensation, it does not support combustion. When the smoke comes in contact with a high heat of more than 500°F or an open flame, it will probably dry out and become invisible. Only very low quantities of residue would be expected with the use of this material. Zinc is not environmentally acceptable and would require control in the wastewater

effluent. In addition, dissipation of smoke in the atmosphere would be relatively slow. A potential thermal decomposition product of this smoke would be zinc oxide.

Zinc chloride exposure can cause damage to the mucous membranes and ulceration of exposed surfaces of skin. The threshold limit value of zinc chloride is 1 mg/m^3. Several recent investigations of the material also indicate a potential carcinogenic effect. Constant exposure to the smoke generated from zinc chloride can irritate breathing passages, and indoor use of these smokes requires the use of a self-contained breathing apparatus. A recent incident in the Navy has promulgated an order by the Naval Bureau of Medicine that zinc chloride not be used for any more Naval training exercises due to its acute toxicity hazard potential.

2.2.3.2.12 Acrowax B. Acrowax B is one of a number of food wax additives being evaluated as a pyrotechnic particulate smoke by the Department of the Army at the Aberdeen Proving Grounds. These waxes generally have a very low toxicity. Acrowax B is a solid material that emits a particulate smoke when burned. It has an extremely low flammability and leaves no residue. It is, however, extremely difficult to control the smoke release once the wax has been ignited. The wax produces a dense smoke and will not vaporize, even at high temperatures. The smoke dissipates slowly in the atmosphere and would contribute to the total solids content of the wastewater effluent. Use of this smoke would require the use of a respirator. No data on potential thermal decomposition products currently exist.

2.2.3.2.13 Wood chips. Wood chips have been used for many years to produce the smoke used in smokehouse operations. Dampened wood chips are generally heated until a smoke is emitted. This smoke is controlled by ventilation adjustments to the heating chamber. The smoke is considered nonflammable and does not leave significant residues. The release of the smoke is moderately controllable by sequenced baffles adapted to the ventilation system. The smoke dissipates at a moderate rate in the air and is not environmentally compatible, therefore requiring some pollution-emission control.

The smoke would not vaporize at proposed operating temperatures in the fire fighter trainer. In addition, the general density of the smoke is extremely light, and obscuration levels desired could not be obtained with this type of smoke-generation system. Proper use of this smoke would require the use of a self-contained respirator. Specific data on this type of system are limited; however, a considerable number of thermal decomposition products could be produced during the generation of this smoke.

2.2.3.2.14 Oil combustion. The combustion of oil on the surface of a hot manifold has been a common method of generating smoke for many years. Little data are available on the specific relative flammabilities and flash points of the materials used in this smoke-generating process. Flammability would most likely be a function of the specific oil that is used. In addition, the use of this oil smoke-generation system generally results in considerable amounts of residue with prolonged use. The controlled release of this smoke is moderate.This smoke probably would not vaporize at the proposed operating temperatures; however, this assumption has not been tested and shown to be the case.

Potential flash problems would exist with the use of this material. In addition, this smoke presents a potential environmental problem because it dissipates slowly in the atmosphere and is not readily disposable in the wastewater effluent. Specific toxicity problems are associated with any oil combustion process, and a respirator would probably be required with its use. Thermal decomposition products could be formed from this material and should be considered potentially toxic.

2.2.3.3 Rank ordering of simulated smokes. The salient characteristics outlined in Table 8 were used to develop a rank order of the simulated smoke candidates, as shown in Table 9. This figure assigns a directional value for each material versus specific criteria. The evaluation was based on whether or not the criteria were met, whether they were conditionally met, or whether data are currently available or whether the available data are uncertain.

A comparative evaluation was made using Table 8 to determine the optimal smoke candidate. Figure 11 summarizes this comparative evaluation process. As shown in the figure, many smokes could be considered comparable; however, in the overall evaluation, triarylphosphate smoke was considered the outstanding candidate.

2.2.3.4 The recommended simulated smoke candidate. After triarylphosphate (Chem Chex 220) was selected as the prime candidate for use in the 19F1 AFFT, it was tested onsite to determine its applicability as the candidate for use during training exercises.

Triarylphosphate (TAP) is generated as a smoke and is made up of a hot air/aerosol mixture. The basic operating principle of the generation system is that triarylphosphate is pumped under high pressure and sprayed into a hot air stream, causing

TABLE 9. SIMULATED SMOKES CRITERIA/SUMMARY OF EVALUATION

	VAPORIZATION/CONDENSATION						CHEMICAL				CHEMICAL PARTICULATE	PYROTECHNIC PARTICULATES		
CRITERIA	PEG-200	MINERAL BASED OIL (PEPPER FOG)	FATTY ALCOHOLS	PROPYLENE GLYCOL	PROPYLENE GLYCOL 10% WATER	CO₂ AND WARM WATER	STANNIC CHLORIDE	ETHYLENEDIAMINE AND ACETIC ACID	NAVAL TACTICAL FM SMOKE	TRIARYLPHOSPHATE (CHEM CHEX 226)	ZnCl₂	ACROMAX 8	WOOD CHIPS	OIL COMBUSTION
1. RELATIVE FLAMMABILITY POTENTIAL	+/-	+/-	-	+/-	+/-	+	?	-	-	+	+	+	+	-
2. RESIDUES	+	-	+	+	+	+	+	+	-	-	+	+	+	-
3. EASILY CONTROLLABLE RELEASE	+	+	+	+	+	-	-	-	-	+	-	-	-	-
4. VAPORIZATION AT <200°F VAPORIZATION >400°F	+ -	+ ++	- -	- -	+ -	- -	? ?	? ?	? ?	+ ++	++ ++	++ +	++ +	+- -
5. SMOKE INTENSITY	+	+	+	+	+	+	-	-	+	+	+	+	-	+
6. ENVIRONMENTAL COMPATIBILITY AND DISPOSABILITY	+/-	+/-	+	+	+	+	-	-	-	+	-	(TO BE CONTROLLED)		-
7. TOXICITY	-	-	-	-	-	+/-	-	-	-	-	-	-	-	-
8. DIFFERENT EQUIPMENT NEEDED	-	-	+	+	+	-	+	-	+	-	-	-	-	-
9. SOME USES OPERATING	+	-	+	+	+	+	+	+	+	-	+	+	-	-
10. POTENTIALLY TOXIC DECOMPOSITION PRODUCTS	?	?	?	-	-	+	-	-	?	?	-	?	?	-

KEY: + MEETS CRITERIA
      - DOES NOT MEET CRITERIA
      ‡ CONDITIONALLY MEETS CRITERIA
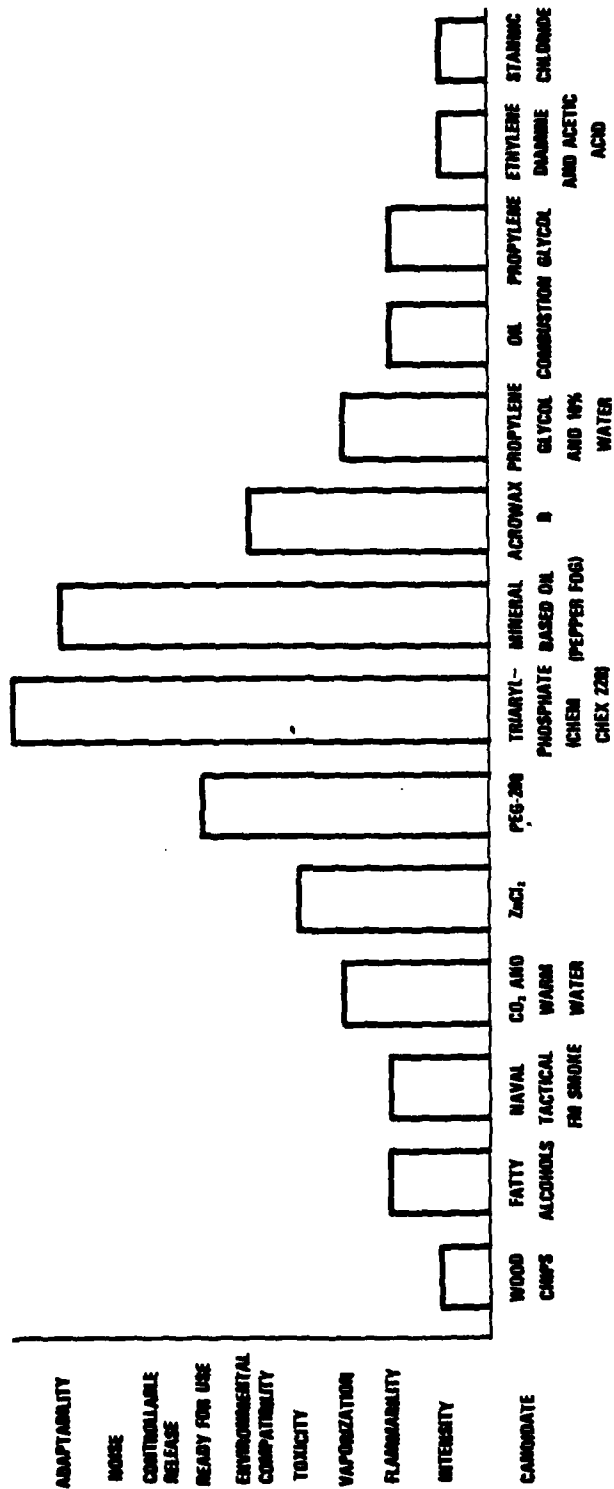   ? NO DATA/UNCERTAIN DATA

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Figure 11. Selection of Optimal Propylene Glycol Surrogate Smoke

a fine dispersion of the liquid material. The generator unit is gasoline-powered for operation of the compressor, burner, and engine units. However, modified units are available using both propane and/or possibly electricity for various operational components of the unit. A smaller version of the unit is available if lesser quantities of smoke are required.

The generator controls can be adapted with electronic controls when used in a remote area. Once mechanical controls on the generator are set to optimum operating positions, they can be left in those positions. The generator has a particle selector valve setting that varies from 1 to 16 (this is not calibrated to any specific particulate size, but is expected to range from 0.5 to 2 μm). The consumption rate at the selected valve setting of approximately 3 is estimated to be about 1 liter per minute.

Figure 12 presents a propane gas-operated unit, which is similar to the gasoline-operated unit used during onsite sampling. The propane gas-operated unit would be more suitable for the training facility because of its more permanent application. Transportability was also considered an important criterion for the test program. Further details on the specifications of the generating equipment as well as triarylphosphate are included in Appendix D.

2.2.3.5 Onsite pretest of simulated smoke candidates. Triarylphosphate was generated onsite during several pretrials prior to the actual onsite sampling program. These pretests were conducted to determine both triarylphosphate's viable use and the building ventilation requirements for the specific smoke-generating unit. The unit was set up to introduce smoke into the entire fire fighter training building at only one location: below Lower Deck Quadrant I. It was further determined during these pretests that, with the ventilation system on at all times, it would take approximately 10 seconds of smoke administration to completely fill the building and meet the established criteria of 6-foot visibility at 20 seconds after initiation of the scenario. The generator was able to create this obscurity condition quite easily. Further refinement through a directed smoke delivery system to designated quadrants will significantly reduce the smoke-generating time well below the 10 seconds used during the onsite sampling scenario program.

2.2.3.6 Conclusions. Based on our evaluation of the possible simulated smoke candidates and the favorable results of the onsite pretest evaluation, triarylphosphate was chosen as the optimal smoke simulant for conducting the onsite
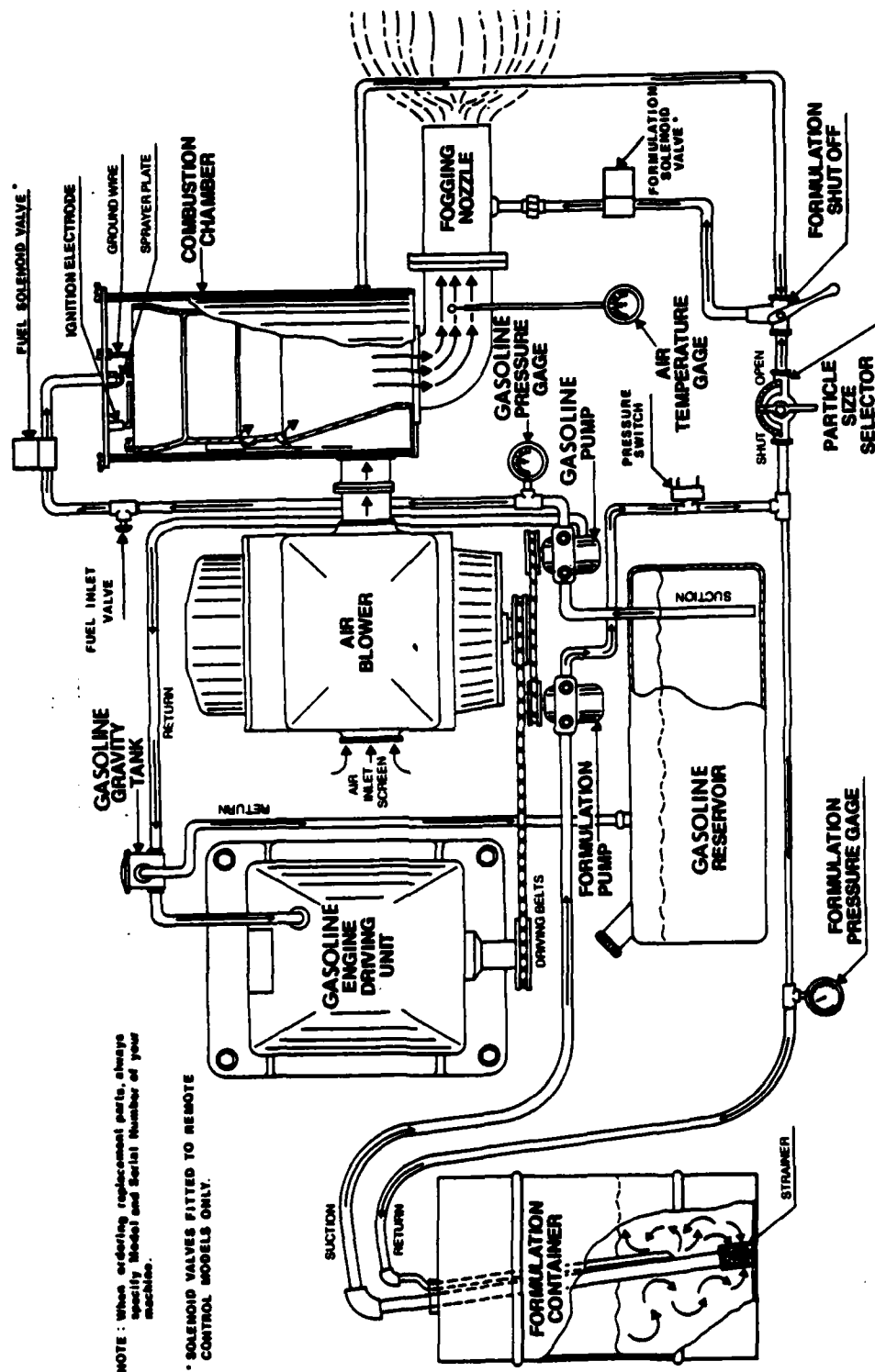
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Figure 12. Smoke Generator

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sampling program. The triarylphosphate smoke recommended for use in the trainer specifically refers to the Chem Chex 220 product of the Tifa Ltd. Company. Although Tifa may not be the sole manufacturer of this material, any substitute triarylphosphate material from another manufacturer should be required to be identical to their product. Even though all triarylphosphates are inherently nonflammable, at least one (e.g., triorthocresylphosphate) is highly toxic and should be avoided.

3. ONSITE TESTING AND CHEMICAL ANALYSES

This chapter presents the methodologies used and results obtained during onsite testing of the proposed substitute foams, powder, and smoke. Each of the scenarios described in the preceding chapter was subjected to a series of test runs, during which measurements were made of temperature, internal gas concentrations, external stack emissions, and smoke concentration. Effluent samples were taken at the end of each series of runs. These samples were characterized to provide a dynamic profile of the environmental activities that take place during each scenario.

3.1 Sampling/analysis plan highlights. The onsite testing of the substitute extinguishing agents took place from April 27 to April 30, 1981, with sample pretesting performed on April 24, 1981. This testing was performed in accordance with a previously approved sampling plan, presented as Appendix C. Representatives of ATS, Booz, Allen & Hamilton, and Case Consulting Laboratories participated in the onsite testing, as shown in Figure 13. As a result of the pretest, one of the two preferred foam substitutes scheduled for testing was elimi- nated, so only 10-percent Ultrawet K was used during the onsite sampling period.

Two specific series of runs were conducted in the evaluation:

- Upper Deck Quadrant II with the modified deep fat fryer and rag bale fire scenarios. These scenarios were modified by an extension of the time lag between the first and second segment of the scenario to permit the changeover of emission sampling equipment in the different sections of that quadrant.

- Lower Deck Quadrant I (bilge fire scenario). This scenario was conducted with the oil spray pilot on, which was required due to the unexpected condition of the solid water stream actually extinguishing the bilge fire. The added pilot prevented this undesired extinguishment from occurring.

Six satisfactory runs were completed for each scenario. In addition, temperature measurements were recorded during all 12 scenario runs.

Booz, Allen and Case Consulting also assisted NTEC in conducting a series of tests using a high-pressure water jet spray to assess its possible use as a mechanical cooling device to be used within the facility during operation. These tests included the input of the test smoke to assure that it would not be knocked down by the water fogging unit.

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│  Senior ATS Rep.    │  │  BAH Test Director  │
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│    R. Ambrozy       │  │    M. Halpern       │
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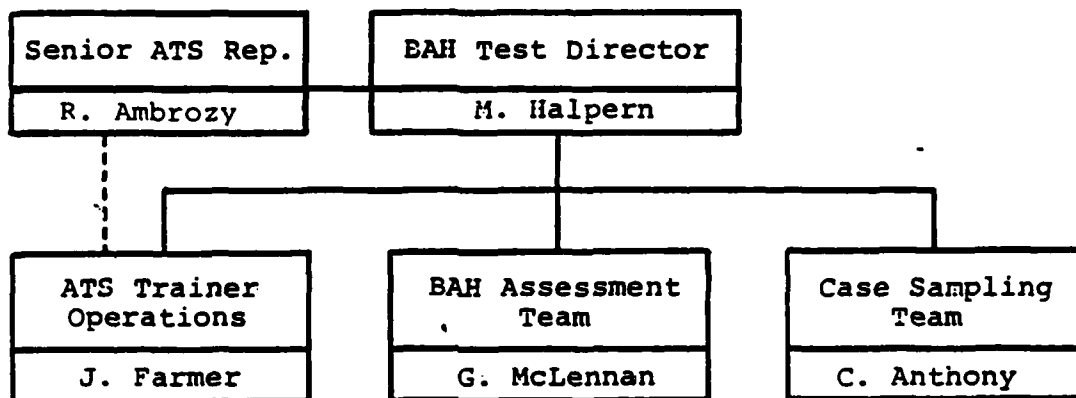

Figure 13.   Task Force Organization of Onsite
                      Sampling Programs

Based on the sampling plan, specific tasks to be accomplished during the onsite testing included the following:

- Measuring test cell atmosphere for concentration of simulated smoke (TAP)

- Profiling temperatures of the test cell in use and adjacent areas at defined flame temperatures

- Monitoring atmospheric emissions from each test cell, making four to six runs on bilge, deep fat, and rag bale fires

- Monitoring CO, CO_2, O_2 and flammable gas concentrations in the test cell during fire trials to verify fixed detector responses via recorded traces

- Collecting wastewater samples from the effluents of the test cells.

Table 10 displays the detailed explanation of individual tests, the equipment used, the purpose of the measurements, and their relationship to the total objectives of the program.

An onsite test schedule shown in Figure 14 was followed. Two separate series of six runs were made with the 19F1 (one for each scenario). These scenarios realistically simulate the proposed training scenarios in Lower Deck Quad I (LDQI) and Upper Deck Quad II (UDQII), as discussed in Section 3.2 of this report.

Integrated wastewater and particulate samples were taken for each set of scenario runs including a 2-minute washout of the facility after each run. Stack emissions were continuously monitored by both ATS and Booz, Allen & Hamilton detection equipment. The air emissions data were recorded separately for each run. In addition, a blank water sample was taken and subjected to the same battery of tests as were the actual wastewater samples. Smoke concentration samples (TAP) were collected from the test cell atmosphere with a separate smoke-injection cycle of the same duration (10 seconds) as used in the scenario runs.

Temperature profiles were obtained by recording the response of thermocouples placed within the test cell used for each type of fire and in selected adjacent locations to sense what influence the contained fire would have on surrounding areas. The recorder was run continuously to visualize the rate of cooldown between runs.

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TABLE 10. ONSITE WORK PLAN SUMMARY

WORK TASKS & ELEMENTS	DETERMINATION TO BE MADE	PURPOSE OF DETERMINATION	METHODOLOGY	EQUIPMENT OR INSTRUMENTATION	RELATIONSHIP TO PROGRAM OBJECTIVES
1. TEST CELL PARAMETER					
• SIMULATED SMOKE CONCENTRATION	TAP CONCENTRATION	ESTABLISH IF A CONCENTRATION IS REACHED THAT COULD BE DANGEROUS OR CAUSE ADDITIONAL OPERATING PROBLEMS. PROVIDE A TARGET FOR CONTROLLING SMOKE GENERATION	COLLECT ON CELLULOSE FILTER, EXTRACT WITH ETHER AND ANALYZE WITH GAS CHROMATOGRAPHY	SAMPLING PUMP, FILTER, AND GAS CHROMATOGRAPH.	APPRAISAL OF EXPLOSION POTENTIAL AND NEED TO PROTECT OPERATORS
• TEMPERATURE	TEMPERATURE OF WALLS AND AIR, ALSO FLAME TEMPERATURE	DETERMINE RATE OF TEMPERATURE RISE IN TEST CELL AND PEAK REACHED DURING RUNS AND COOL DOWN	THERMOCOUPLES PLACED IN DESIGNATED SPOTS PER ATS DRAWINGS SK20325, SK20326, ATTACHED TO MULTI-POINT RECORDER TO PRODUCE PERMANENT RECORD. DIRECT READING DIGITAL THERMOCOUPLE FOR FLAME TEMPERATURE	ESTERLINE-ANGUS E-112AE MULTIPOINT RECORDER, CHROMEL-ALUMEL THERMOCOUPLES. WET BULB BLACK GLOBE THERMOMETER. OMEGA DIGITAL THERMOCOUPLE	DEFINE THERMAL EXPOSURE TO OPERATORS AND EFFECTS RELATIVE TO PROTECTIVE GUIDELINES. DETERMINE PROFILES THROUGHOUT TEST FACILITY TO PREDICT EFFECTS ON HARDWARE, COMMUNICATIONS AND BUILDING STRUCTURE
• CELL ATMOSPHERE	CARBON MONOXIDE (CO) CARBON DIOXIDE (CO2) OXYGEN (O2) FLAMMABLE GASES	TO AUGMENT FIXED SYSTEM READINGS. DETERMINE IF HAZARDOUS LEVELS ARE REACHED DURING FIRE TESTS	INSTRUMENT METHODS, INCLUDING NON-DISPERSIVE I.R. CATALYTIC DETECTORS AND THERMAL CONDUCTIVITY ARRANGED TO PROVIDE HARD COPY RECORD	MINEN MISSON NON-DISPERSIVE INFRARED UNITS -- CO DUAL RANGE, 0-1%, 0-5%; CO2 DUAL RANGE; 0-2%, 0-10%. TELEDYNE O2 AND COMBUSTIBLE GAS DETECTOR -- O2; 0-30%; COMBUSTIBLE GAS, 0-5%. HEWLETT PACKARD DUAL CHANNEL STRIP RECORDERS	DETERMINE WHAT CHANGES OCCUR IN ATMOSPHERIC COMPOSITION DURING TEST FIRES. DATA WILL DEFINE IF ANY HAZARD OF CONSEQUENCE EXISTS AND IF ADDITIONAL PROTECTION IS NEEDED FOR OPERATING PERSONNEL
2. ATMOSPHERIC EMISSIONS	PARTICULATE MATTER	TO MEASURE WHETHER EMISSIONS EXCEED EPA LIMITS	EPA METHOD 5. TAKING AIR SAMPLES FROM STACK EXHAUST, CAPTURING THE PARTICULATES AND DETERMINING THEM BY GRAVIMETRIC MEANS	EPA METHOD 5 TRAIN WITH CONTROL AND RECORDING UNIT	PROVIDE A BASIS TO COMPARE EMISSION RATE WITH LOCAL AND FEDERAL REGULATIONS AND SELECTION OF ENGINEERING CONTROL METHODS TO MEET EMISSION LIMITS
3. WATER EFFLUENT	PH, COD, BOD, BICARBONATES, CARBONATES, TOTAL, SUSPENDED AND DISSOLVED SOLIDS, TURBIDITY, SURFACTANTS, SULFATES, PHOSPHATES, TAP				
• WASTE WATER FROM EACH TEST QUADRANT		TO PROVIDE VALUES FOR FILING WASTE WATER PERMIT OR TD DETERMINE NEED FOR PRETREATMENT	CHEMICAL ANALYSIS OF SAMPLES TAKEN FROM TEST CELL SUMPS FOLLOWING TEST FIRES AND WASH DOWN	MISCELLANEOUS LAB ITEMS AND PH METERS, ANALYTICAL BALANCES, APPROPRIATE REAGENTS	PERMITS EVALUATION OF LOAD WASTE WATER FROM THESE TRAINING UNITS WILL IMPOSE ON LOCAL SEWAGE TREATMENT PLANTS. DATA NEEDED FOR PERMIT AND TO ESTIMATE SIZE AND TYPE OF PRETREATMENT UNIT NEEDED AS NECESSARY BY LOCAL CODES

SOURCE: CASE WESTERN JIVE LABORATORIES.

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Mon.
4/27      8 a.m.- 2 p.m.      Travel to site
                              Initial setups to UDQ II
                              Prepare extinguishment agents for use

          2 p.m.- 5 p.m.      Testing TAP to determine timing/venting
                              parameters to meet smoke criteria


Tue.
4/28      7 a.m.-10 a.m.      Group briefing and walk through dry run

         10 a.m.- 2 p.m.      Run UDQ II scenarios and temperature runs

          2 p.m.- 5 p.m.      Reset test equipment for LDQ I runs

          4 p.m.-10 p.m.      Tentative NTEC temperature tests


Wed.
4/29      8 a.m.-10 a.m.      Complete equipment setup for LDQ I runs

         10 a.m.- 2 p.m.      Run LDQ I scenarios

          2 p.m.- 6 p.m.      Follow temperature cooldown


Thur.
4/30      8 a.m.-12 p.m.      Repeat runs if required
                              Equipment disassembly

          1 p.m.- 4 p.m.      Tentative NTEC temperature tests
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Figure 14.   Onsite Testing Schedule

Six thermocouples were used for the temperature profiling of UDQII. The actual placement of the thermocouples was designated by ATS at the site, and the locations are shown in Figure 15 for the deep fat/bale fires. In the LDQI, bilge fire site, nine thermocouples were placed to sense surface temperatures and air streams and to obtain vertical gradients. Figure 16 shows their location. Gas-sampling locations were designated for each test cell as shown in Figures 17 and 18.

As a result of the onsite pretest and a meeting held prior to initiation of activity, the following modifications in the original sampling plan were made:

- The UDQII scenario was modified by increasing the time lag between the deep fat and rag bale fires. This was done to allow for the changeover of emission sampling equipment to different sampling points within the quadrant.

- The automatic shutdown threshold of the facility was changed from 10 percent of the lower explosive limit (LEL) to 25 percent of the LEL.

- The Triton X-100 foam was eliminated from testing due to insufficient foaming action experienced during pretesting.

- The duration of smoke flow (TAP) to the building was set at 10 seconds after determining that this was adequate to provide less than 6-foot visibility at 20 seconds after initiation of the pilots. The smoke was not piped into the specific quadrants but was administered from a single outlet beneath LDQI.

- The twin nozzle extinguishing system was used for the bilge fire scenario. Although a secondary quantity of Ultrawet K was required to adequately fill the entire piping field for use, the twin nozzle system was found to be completely operational. Both the foam and the sodium bicarbonate were sufficiently administered to the bilge fire through this system. For the deep fat fryer fire, the Venturi pickup tube was used to administer the foam and 15-pound tanks of sodium bicarbonate were used for the powder.

- As a means of reducing the consumption of gasoline in the smoke generator during testing, the generator was shut down between each test run. The gas consumption will be considerable if the equipment is in operation all day long. Propane would be the optimal choice.
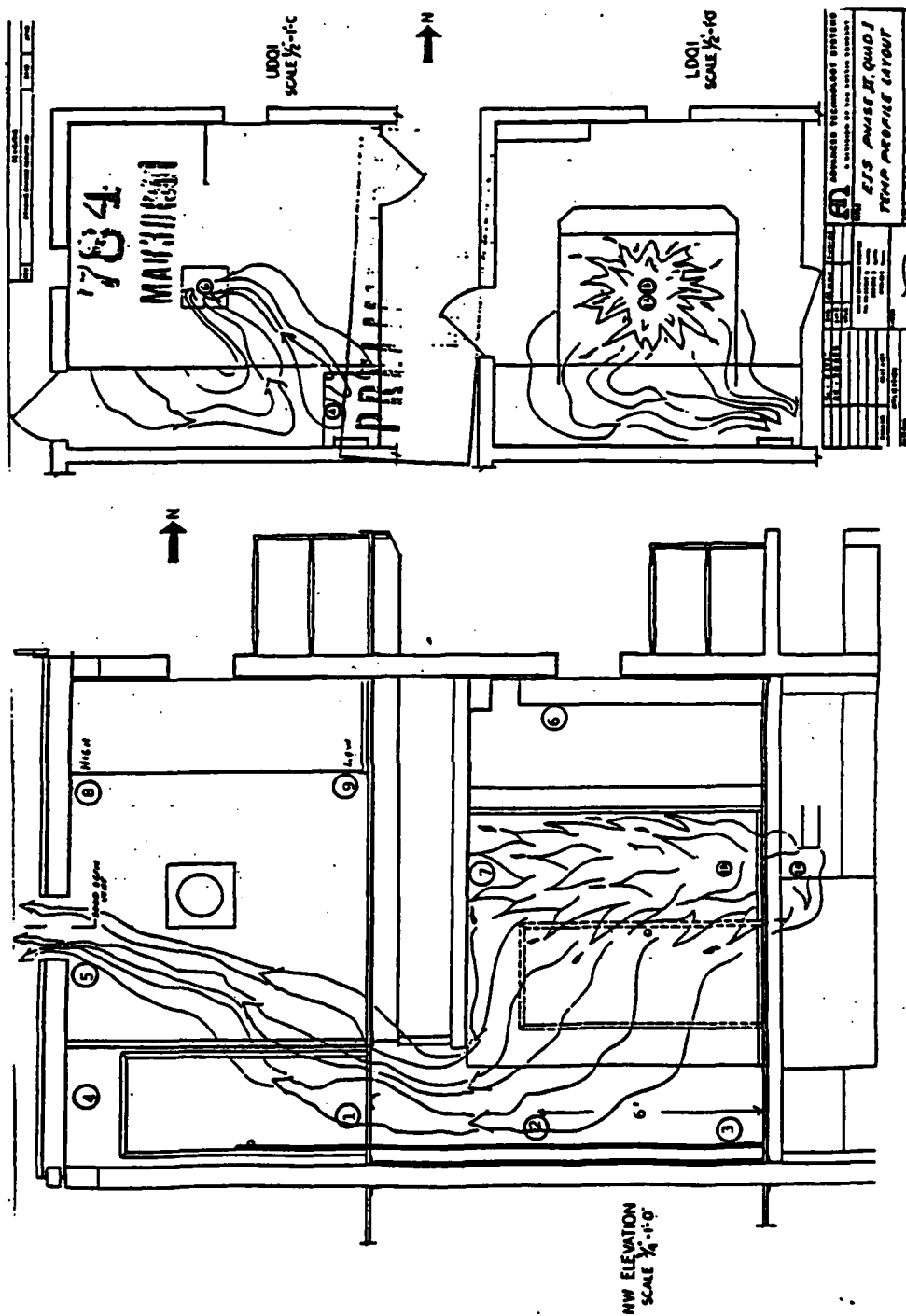
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Figure 15. UDØII Thermocouple Locations

Figure 16. LDQI Thermocouple Locations
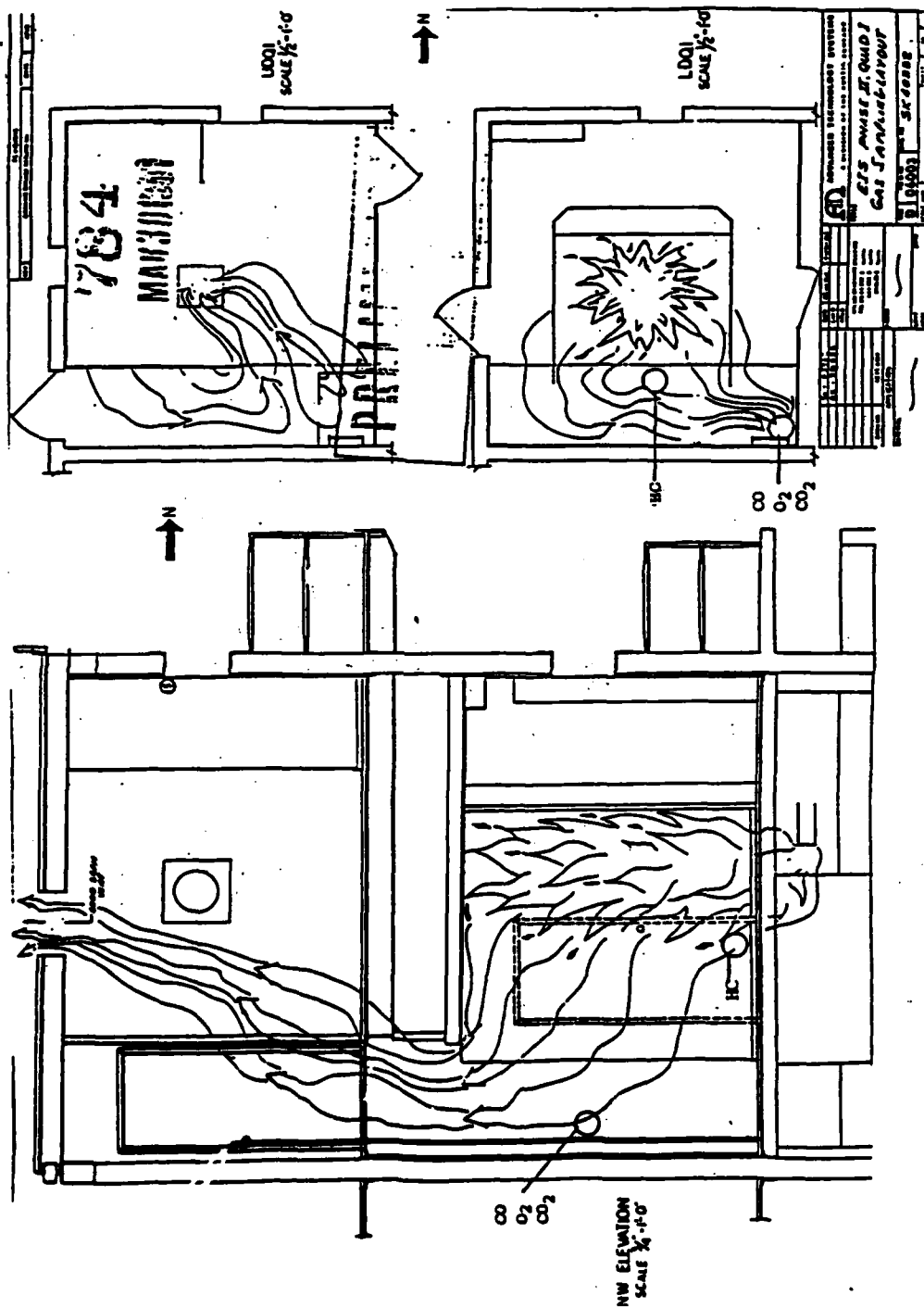
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Figure 17. LDQI Gas Sampling Locations

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Figure 18. UDQII Gas Sampling Locations

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Additional observations were made during the onsite testing, including:

- The grade No. 2 sodium bicarbonate settles significantly faster than the formerly used PKP powder. This was also confirmed subjectively by Case Consulting's observation of the paper filter samples taken from the stack emissions.

- The 10-percent Ultrawet K consistently activated all the sensor units.

- No flammability problems were observed with use of the TAP smoke. The consumption of TAP appears to be approximately one-quarter of a gallon per minute (1 LPM at a setting of approximately 3). This was estimated to be about twice the consumption rate of the propylene glycol generator; however, the actual running time is about 20 percent of that for the propylene glycol generator.

- The operational temperatures during the bilge fire scenario were considerably lower than during the Phase I tests because a low-velocity fog was maintained throughout the majority of the test scenarios, apparently keeping the temperature of the quadrant lower. This was further confirmed in later tests with NTEC in which much higher temperatures in the quadrants were obtained without the use of the low velocity fog.

- It was observed that the smoke can interfere with the proper sensing of a pilot light due to its density. This further justifies the need for proper piping of the smoke into the building. The smoke should be able to be piped into any part of the building without the need of any heated lines as would be necessary with the propylene glycol.

- The wastewater effluent was monitored for its pH and turbidity prior to its release into the sewer system. The pH was observed to be 8.4, and the turbidity was not considered to be extraordinarily high. As a safety factor, approximately 500 gallons of water were added to the wastewater effluent following the deep fat fryer scenarios to guarantee a more diluted suspended solid concentration in the effluent. This step was not considered necessary following the bilge fire scenarios due to the large quantities of water used in the scenario. A blank water sample was taken on the first and second days and combined for use as a test blank.

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The methodologies used during the onsite testing period and the results of analyses of the data and samples collected are presented in Sections 3.4 and 3.5.

3.2 <u>Test scenarios - sampling plan and revisions.</u> Prior to onsite testing of the recommended substitutes, scenarios were developed for each fire (bilge, deep fat/stack hood, and rag bale) to provide a realistic simulation of the events that would occur in an actual fire fighter training program using the 19F1. The timing of certain events in each scenario was subsequently revised to accommodate the specific needs of the trainer and the observations made onsite immediately prior to testing. Original and revised scenarios are presented in Figures 19 through 22.

3.2.1 Lower Deck Quadrant I (LDQI) scenario. This scenario simulates a shipboard bilge fire. Changes that were incorporated into the scenario, both prior to and during onsite testing, included:

- Based on initial tests, it was determined that 10 seconds of TAP input to the building (rather than the 20 seconds allowed for in the original scenario) was adequate to provide less than 6-foot visibility at 20 seconds after initiation of the pilots.

- The initial 10-second main flame did not occur due to a computer-controlled safety valve lag time of 19 seconds. Therefore, the first 140 seconds of the scenario were performed with the pilot flames only.

- The PKP surrogate application was reduced from 15 to 7 seconds, the actual time needed for application of the entire 15 pounds of material.

- The solid stream (90 gallons per minute) water application was reduced from 20 to 15 seconds.

- The length of application of a 65 gallons-per-minute high velocity water spray (275 seconds) and an AFFF surrogate (375 seconds) varied from run to run, with the endpoint dependent on the control tower operator's monitoring of actual extinguishment of the fire by the agent.

The LDQI scenario changes are detailed in Table 11.

3.2.2 Upper Deck Quadrant II (UDQII) scenario. This scenario simulates a deep fat fryer/stack hood fire and a rag bale fire. As in the LDQI scenario, changes in the timing of
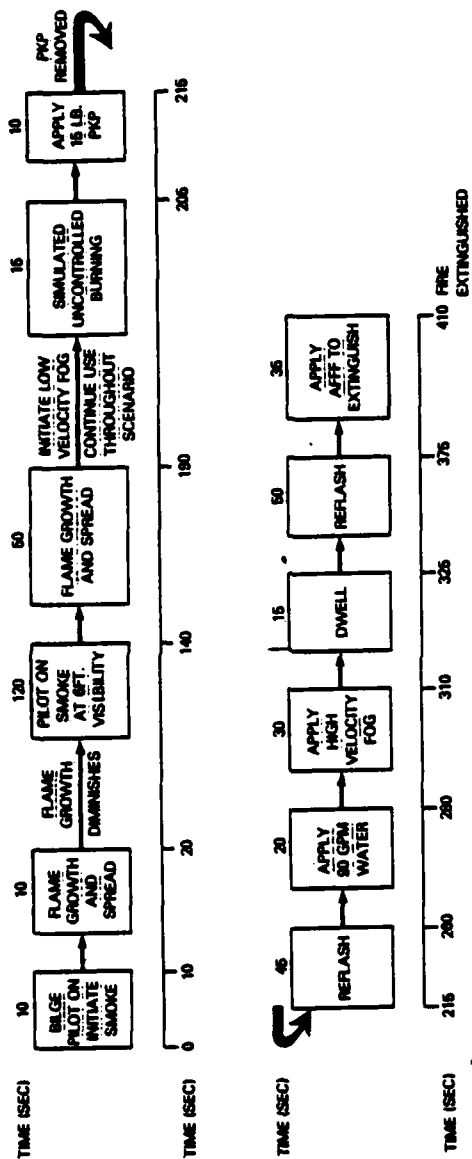
77

NOTE: AFFF and PKP are used only as generic descriptors.
Candidate substitutes were actually used in test runs.
(AFFF = 10% Ultrawet K, PKP = Sodium Bicarbonate).

Figure 19. LDQI Original Scenario
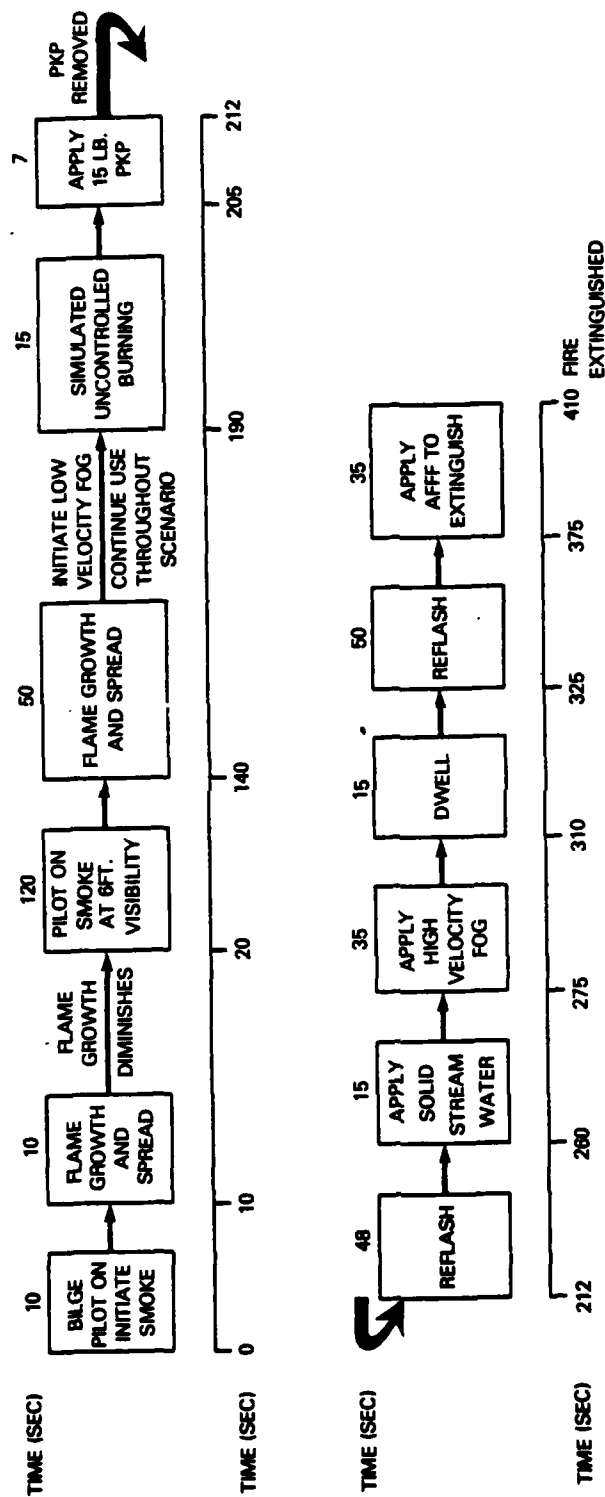
78

Figure 20. LDOI Revised Scenario
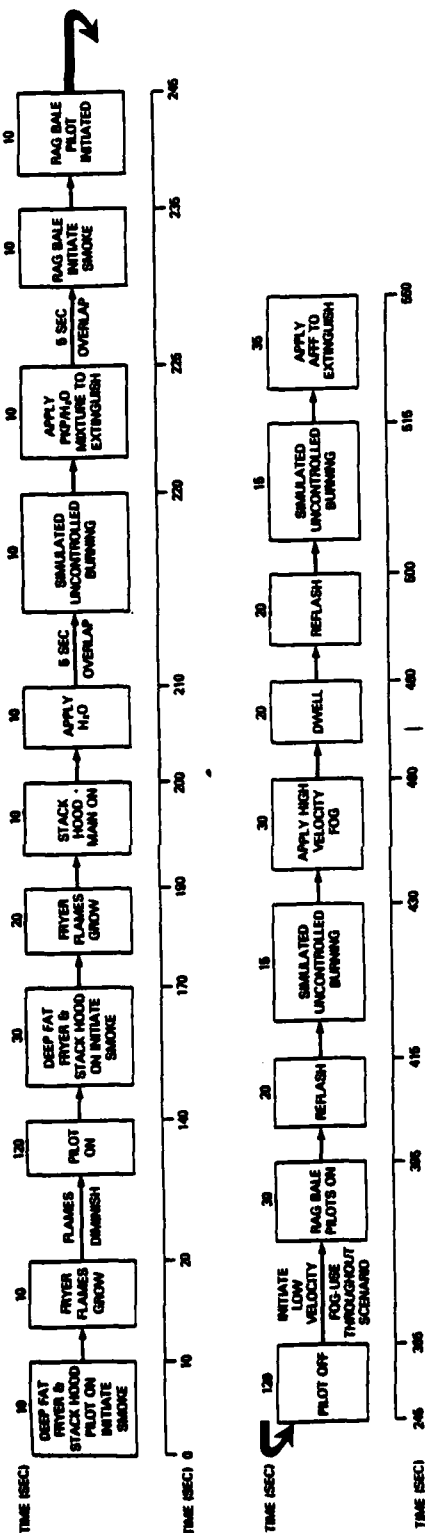
NOTE: AFFF AND PKP ARE USED ONLY AS GENERIC DESCRIPTORS. CANDIDATE SUBSTITUTES WERE ACTUALLY USED IN THE TEST RUNS (AFFF=10% ULTRAWET K, PKP=SODIUM BICARBONATE).

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NOTE: AFFF and PKP are used only as generic descriptors.
Candidate substitutes were actually used in test runs.
(AFFF = 10% Ultrawet K, PKP = Sodium Bicarbonate).

Figure 21. UDQII Original Scenaric
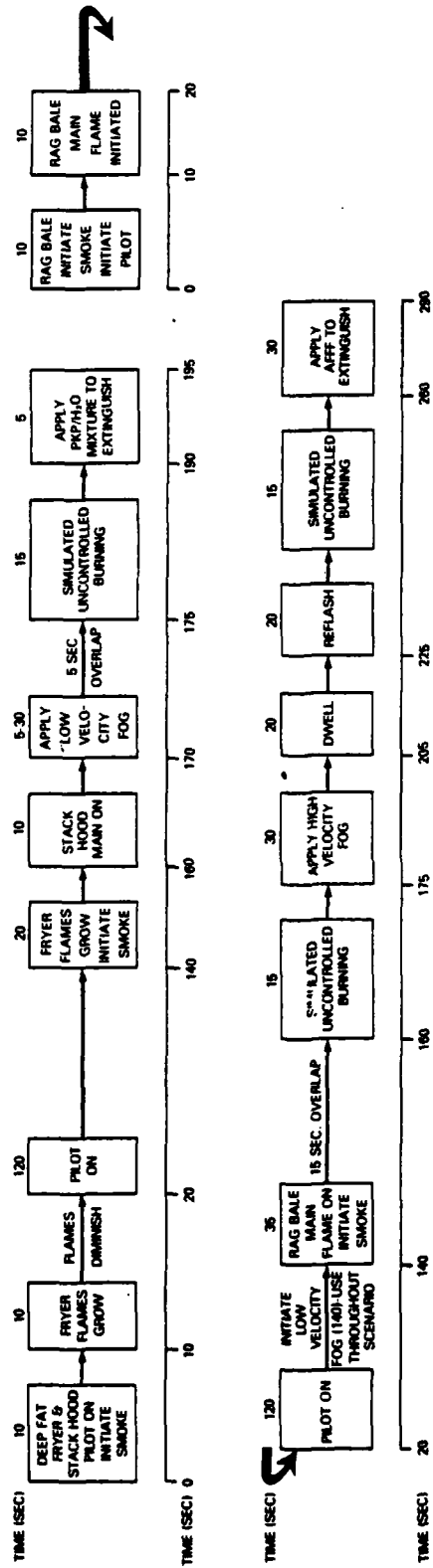
Figure 22.   UDQII Revised Scenario

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TABLE 11.   LDOI SCENARIO CHANGES

Activity Description	Original Time (seconds)	Revised Time (seconds)	Reason for Change
Bilge pilot on, initiate smoke (burners are ignited and burn in pilot position).	0	0	
Initiate main flames (flames grow and spread for 10 seconds, then diminish).	10	10	
Stop smoke (smoke at 6 feet visibility).	20	10	Visibility requirements met with 10-second burst of smoke.
Pilot on.	20	20	
Main flames on (flames grow and spread). Apply low-velocity fog continuously through scenario.	140	140	
Simulate uncontrolled burning (flames reflash, grow, and spread under program control)	190	190	
Apply 15-1b. PKP, covering all burners in an attempt to extinguish fireplace.	205	205	

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TABLE 11.(Continued)

Activity Description	Original Time (seconds)	Revised Time (seconds)	Reason for Change
PKP is removed (flames reflash, grow, and spread at programmed rates).	215	212	PKP canisters emptied in 7 seconds.
Apply solid stream (90 GPM) water in digging fashion in an attempt to extinguish fireplace (once high-flow water is sensed at one burner, all flames grow in unison to torch position within 5 seconds, and burn at torch position for 10 seconds).	260	260	
Apply 65 GPM high-velocity water spray in an attempt to extinguish fire (flames recede to low-fire position).	275	280	
Stop applying high-velocity spray.	290	290-310	Varied depending on control tower command.
(System dwells for 15 seconds.)	310	310	
(Flames reflash, spread, and grow at programmed rates. All burners achieve high-fire position in 50 seconds.)	325	325	

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TABLE 11.(Continued)

Activity Description	Original Time (seconds)	Revised Time (seconds)	Reason for Change
AFFF is applied for 30 seconds covering all burners in an attempt to extinguish fireplace. (System steps down to low-fire position in 30 seconds and shuts down in an additional 5 seconds.)	375	375	
Stop applying AFFF.	405	390-400	Varied depending on control tower command.
Fireplace is extinguished.	410	410	

NOTE: AFFF and PKP are used only as generic descriptors. Candidate substitutes were actually used in test runs. (AFFF = 10% Ultrawet K, PKP = Sodium Bicarbonate).

certain events were made for onsite testing. These changes include the following:

- The initial 10-second main flame did not occur due to a computer-controlled safety valve lag time of 19 seconds. Therefore, the first 140 seconds of the scenario were performed using the pilot flames only.

- The input of smoke (TAP) to the building was reduced from 20 to 10 seconds for the same reason as for the LDQI scenario.

- The fryer flames (140 seconds) began to grow immediately upon their initiation, reducing the time needed by 30 seconds.

- The length of application of the low-velocity fog was increased by 5 seconds each run. This, in turn, caused the remaining scenario activities to be altered accordingly.

- A break was inserted between the deep fat and rag bale fires to change detection equipment leads, necessitating a restart of the rag bale fire at time zero.

These changes are detailed in Table 12.

3.3 Sampling parameters. The parameters measured during Phase II onsite testing were selected based on potential areas of concern encountered during Phase I, with modifications made to account for extinguishing agent substitution. Each test area and the parameters measured are shown in Table 10 and discussed below.

3.3.1 Waterborne effluent. The combined effluent from all runs of a single scenario was collected in a blocked-off trough situated underneath the test facility. The parameters measured were pH, suspended solids, total solids, dissolved solids, turbidity, sulfates, carbonates, bicarbonates, surfactants (Ultrawet K), total phosphates, triarylphosphate, biochemical oxygen demand (BOD), and chemical oxygen demand (COD). These parameters were selected to provide values for use in submitting wastewater permit applications for the facility and to determine whether the effluent generated by the scenario will require pretreatment prior to entering local POTWs. The measurements will also help determine the load that effluents from the training facility will impose upon local sewage treatment plants.

3.3.2 Air emissions. Samples of atmospheric emissions were collected from the stacks above each quadrant and analyzed for particulate matter. This analysis will assist in

TABLE 12. UDQII SCENARIO CHANGES

Activity Description	Original Time (seconds)	Revised Time (seconds)	Reason for Change
Deep fat fryer and stack hood pilot on, initiate smoke.	0	0	
Initiate fryer main flame. (Fryer flame grows to main position and burns for 10 seconds, then diminishes.)	10	10	
Pilot on for 120 seconds.	20	20	
Initiate fryer main flame. Initiate smoke for 10 seconds.	140	140	
Fryer flames grow and spread for 20 seconds.	170	140	Overlap with previous activity.
(Stack hood burner on to main position for 10 seconds.)	190	160	
Apply low-velocity fog to fryer in an attempt to extinguish. (Fire torches until fog is removed.)	200	170	
(Fryer and stack hood burn in main position.)	210	175	
Remove low-velocity fog.	210	180-205	Application varied to determine effect.

TABLE 12.(Continued)

Activity Description	Original Time (seconds)	Revised Time (seconds)	Reason for Change
Apply PKP/H_2O mixture to fryer and stack hood in an attempt to extinguish. (Burners step down to low-fire position in 5 seconds and shut down in an additional 5 seconds.)	220	190-215	
Stop applying PKP/H_2O mixture.	225	195-200	
(Deep fat fryer and stack hood fireplaces are extinguished.)	230	200-225	
Rag bale pilots are initiated; smoke is initiated for 10 seconds.	225	0	Break inserted between fires.
Rag bale main flame is initiated. (Burners run in main position for 10 seconds.)	235	10	
Pilot on for 120 seconds.	245	20	
Initiate low-velocity fog, used continuously throughout scenario.	245	140	
Rag bale pilots on for 30 seconds.	365	-	

TABLE 12. (Continued)

Activity Description	Original Time (seconds)	Revised Time (seconds)	Reason for Change
Initiate rag bale main flame. (Flames grow and spread in accordance with programmed rates to high-fire position in 20 seconds and dwell at high-fire position for 15 seconds.)	395	140	
Apply high-velocity fog for 30 seconds. (Flames recede to low-fire position.)	430	175	
(Burners dwell at low-fire position for twice the programmed soak time.)	460	205	
(Flames reflash, grow, and spread at programmed rates. Achieves high-fire position in 20 seconds and dwells at high-fire position for 15 seconds.)	480	225	
AFFF is applied for 30 seconds covering all burners. (System steps down to low-fire position in 30 seconds and shuts down in an additional 5 seconds.)	515	260	
(Rag bale fireplace is extinguished.)	550	295	

NOTE: AFFF and PKP are used only as generic descriptors. Candidate substitutes were actually used in test runs. (AFFF – 10% Ultrawet K, PKP = Sodium Bicarbonate).

determining whether the stack emissions exceed limitations established by federal, state, or local regulations and in selecting engineering control methods to meet these limitations. Samples of the test cell atmosphere were also taken during each scenario run and analyzed for carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), hydrocarbons, and oxides of nitrogen. These samples were taken to help determine whether hazardous levels of any of these gases were attained during any point in either scenario. The data will define any existing hazards of consequence and whether additional protection will be needed for operating personnel. The levels of each gas mentioned above were charted on a recorder, with a backup system calibrated to a different scale to ensure retention of all data.

3.3.3 Simulated smoke concentration. Samples of the smoke generated during each scenario were analyzed for triaryl-phosphate (TAP), the substance used for smoke generation. The purpose of this analysis was to establish if a concentration is reached during either scenario that could be dangerous or cause additional operating problems. The data will also provide information to aid in assessing explosion potential and the extent to which operators should be protected against potential explosions.

3.3.4 Temperature. The operating temperatures of the walls and air inside the test cell were measured during each scenario run, and the maximum flame and pilot temperatures for each fire were also measured. These data served to establish the peak operating temperatures reached during each run and to profile the temperature patterns during each run and subsequent building cooldown. Results were compared to the established internal operating temperature of 125°F. These temperature data will be used to define thermal exposure to operators and the relationship of this exposure to protective guidelines, and will also help to predict the effects of heat on building hardware, communications devices, and structure.

3.3.5 Noise. Noise-monitoring equipment was used to measure the noise output associated with operation of the smoke-generating machine. The data collected will give preliminary information concerning potential hazards to hearing and interference with communication experienced by individuals located outside the facility.

3.4 Methodology. This section discusses the methodologies used during onsite testing and follow-up laboratory analyses to collect the environmental data associated with the 19F1 trainer.

3.4.1 Waterborne effluent. Samples of the effluent were taken after each set of scenario runs. These samples were collected from three different locations within each quadrant sump (situated directly underneath the facility). The following accepted methods were used to analyze the samples for the parameters discussed in the previous section:

pH	EPA 150.1
COD	EPA 410.1
BOD	EPA 405.1
$CO_3 + HCO_3$	Standard Method 403
Total solids	EPA 160.3
Suspended solids	EPA 160.1
Dissolved solids	EPA 160.2
Turbidity	EPA 180.1
Surfactants	EPA 425.1
Phosphates	EPA 365.2
Sulfates	EPA 375.4
TAP	NIOSH 5210

These procedures were discussed in our original Onsite Sampling Plan.

3.4.2 Air emissions. An integrated sample of particulate matter was taken for each set of scenario runs. The sampling was done continuously, forming composite samples for all of the test runs. Particulate concentrations of these composite samples were analyzed using EPA Method 5.

Gaseous emissions were measured using two sets of equipment calibrated to different scales, with the larger scale acting as a backup to monitor activity above the range of the smaller scale. A separate set of measurements was made for each test run. Methodologies used to detect each of the gases are as follows:

- Carbon monoxide: Nondispersive IR as referenced in EPA Method 10 adapted to test cell atmosphere and standardized with calibration gas mixtures

- Carbon dioxide: No applicable EPA method; use nondispersive IR as recognized industrial method calibrated with standard gas mixtures

- Oxygen: No applicable EPA method; use catalytic cell determination in accordance with industrial method, calibrated with standard gas mixtures

- Flammable gases: No applicable EPA method; use catalytic oxidation method—thermal conductivity in accordance with industrial method, calibrated with standard mixtures of propane in air.

The locations of the sensing equipment for each parameter are shown in Figures 17 and 18.

3.4.3 Simulated smoke concentration. A separate test run was conducted to measure the concentration of smoke that would be present in the facility during a scenario, using a 10-second burst of triarylphosphate (TAP) to create the visual obscurity required by the scenario. Two sets of smoke samples were collected continuously for a 1-minute period beginning at the onset of a 10-second burst of TAP from the smoke generator. These samples were collected on cellulose filters, extracted with ether, and analyzed for TAP concentration using gas chromatography.

3.4.4 Temperature. The operating temperatures in the facility during each scenario run were measured using thermocouples placed in designated spots inside each quadrant, as shown in Figures 15 and 16. These thermocouples were attached to a multipoint recorder to provide a permanent temperature record. Wet bulb and globe temperature measurements were also taken; these measurements were read directly from the thermometers immediately following each test run. In a separate test, the maximum temperature of the pilots and flame for each fireplace (bilge, deep fat, stack hood, and rag bale) was measured by placing a direct reading digital thermocouple directly into the flame and visually monitoring the readout.

3.4.5 Noise. The noise produced during operation of the smoke generator was measured using a General Radio Precision Sound Level Meter and Analyzer, Type 1933. A-weighted sound levels were determined at distances of 10 and 50 feet from the smoke generator. The octave band measurements were made at a distance of 3 feet from the compressor end of the smoke generator, at frequencies of 63, 125, 250, 500, 1,000, 2,000, 4,000 and 8,000 Hertz (Hz).

3.5 Findings. This section presents the results of the sampling and analysis program carried out during the onsite testing. A series of tabulations and illustrations of the data will be presented for the following parameters:

- Waterborne effluent
- Air emissions

    - Stack emissions
    - Internal atmospheres

- Simulated smoke concentration
- Temperature
- Noise.

Tables 13, 14, and 15 present an index to the timing of each scenario run and the abbreviations used throughout this report for each activity.

3.5.1 Waterborne effluent. The measured concentrations of pollutants in the wastewater samples taken after completion of each set of scenario runs are shown in Table 16. Also included are the analytical results of a blank sample taken during onsite testing. The values obtained for the measured parameters are considerably lower than the original test runs (Phase I) using AFFF and PKP.

3.5.2 Air emissions. The results of the stack sampling taken over the entire timeframe of each set of scenario runs (approximately 4 hours) are summarized in Table 17. The particulate emissions values found were very low, primarily attributed to the use of the course grade sodium bicarbonate as fewer small particles were available for dusting and emission from the stack. The maximum emission rate for the functional half of the facility was determined to be 0.0372 pounds per hour during the deep fat and rag bale fires (UDQII) and 0.0059 pounds per hour during the oil bilge fire (LDQI). This represents an estimated discharge of approximately 8.5 grams per scenario for the deep fat fryer and 1.4 grams per oil bilge scenario.

The internal concentrations of O_2, CO, CO_2, oxides of nitrogen, and hydrocarbons were plotted graphically on an axis of concentration versus time. These graphs are presented in Appendix F, and examples for each scenario are shown in Figures 23 through 32.

The maximum gas concentrations measured in the test cell, as measured by Booz, Allen's backup monitoring equipment, during each scenario run are presented in Table 18. The ranges of maximum emission concentrations found include the following:

Emission	Bilge	Deep Fat	Rag Bale
CO(%)[1]	0.2-0.5	0.2 -1.0	0.2-0.9
CO_2(%)	0.2-2.5	2.0 -3.4	2.6-5.7
HC(%)	0.3-0.8	0.1 -0.5	0.1-0.6
O_2(%)[2]	18.7-17.7	19.3 -18.2	18.0-15.5
% of LEL[3]	3-8	-	2-6
NO_x(ppm)	12-16	6-8	2-3

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[1] For calculation purposes, 1% = 10,000 ppm.
[2] Minimum concentration.
[3] LEL = lower explosive limit; these values were from
     ATS sensors that are not based on hydrocarbon levels.

TABLE 13. LDQI INDEX - TIME VERSUS ACTIVITY

Activity	Abbreviation[1]	Run 3	Run 4	Run 5 (Time/Seconds)	Run 6	Run 7	Run 8
Start Pilot, Start Smoke	Start	0	0	0	0	0	0
Flame On, Stop Smoke	On	10	10	10	10	10	10
Go to Pilot	Pilot	20	20	20	20	20	20
Flame On, Apply Low-Velocity Fog	LVF	140	140	140	140	140	140
Apply PKP Surrogate	PKP	205	205	205	205	205	205
Stop Applying PKP Surrogate	PKP Off	212	212	212	212	212	212
Apply Solid Stream Water	Solid Stream	260	260	260	260	260	260
Stop Applying Solid Stream, Apply High-Velocity Water Spray	HV	275	275	275	275	275	275
Stop Applying High-Velocity Spray	HV Off	290	295	308	305	300	310
Apply AFFF Surrogate	AFFF	375	375	375	375	375	375
Stop Applying AFFF Surrogate	AFFF Off	390	390	395	395	395	400

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[1]Used on gas concentration, gas flow, and temperature graphs.

TABLE 14. UDQII DEEP FAT FRYER INDEX - TIME VERSUS ACTIVITY

Activity	Abbreviation[1]	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
				(Time/Seconds)			
Start Pilot, Start Smoke	Start	0	0	0	0	0	0
Flame On, Stop Smoke	On	10	10	10	10	10	10
Go to Pilot	Pilot	20	20	20	20	20	20
Flame On, Start Smoke	Smoke	105	140	140	140	140	140
Smoke Off	Smoke Off	115	150	150	150	150	150
Fire Spreads to Hood	Spread	125	160	160	160	160	160
Apply Low-Velocity Water Fog	LVF	150	170	170	170	170	170
Stop Applying Low-Velocity Water Fog	LVF Off	160	185	190	195	200	205
Apply PKP Surrogate/H_2O Mixture	PKP	170	195	200	205	210	215
Stop Applying PKP Surrogate/H_2O Mixture	PKP Off	175	200	205	210	215	220

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[1]Used on gas concentration, gas flow, and temperature graphs.

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TABLE 15.   UDQII RAG BALE INDEX - TIME VERSUS ACTIVITY

Activity	Abbreviation[1]	Run 3	Run 4	Run 5 (Time/Seconds)	Run 6	Run 7	Run 8
Start Pilot, Start Smoke	Start	0	0	0	0	0	0
Flame On, Stop Smoke	On	10	10	10	10	10	10
Go to Pilot	Pilot	20	20	20	20	20	20
Flame On, Start Smoke	Smoke	140	140	140	140	140	140
Stop Smoke	Smoke Off	150	150	150	150	150	150
Apply High-Velocity Spray	HV	175	175	175	175	175	230
Stop Applying High-Velocity Spray	HV Off	205	205	205	205	205	260
Reflash	Reflash	225	225	225	225	225	280
Apply AFFF Surrogate	AFFF	260	260	260	260	260	315
Stop Applying AFFF Surrogate	AFFF Off	290	290	290	290	290	345

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[1]Used on gas concentration, gas flow, and temperature graphs.

TABLE 16. WASTEWATER ANALYSIS

Parameter	80-1633 (LQ-1)	80-1635 (LQ-2)	80-1630 (Blank Water)
• Suspended Solids	42 mg/liter	26 mg/liter	5.6 mg/liter
• Total Solids	2,454 mg/liter	4,826 mg/liter	234 mg/liter
• Dissolved Solids	2,412 mg/liter	4,800 mg/liter	228 mg/liter
• Turbidity	18 NTU	27 NTU	10 NTU
• Sulfate	84 ppm	520 ppm	48 mg/liter
• Alkalinity			
– Hydroxide	0.0 mg CaCO$_3$/liter	0.0 mg CaCO$_3$/liter	0 mg CaCO$_3$/liter
– Carbonate	160 mg CaCO$_3$/liter	200 mg CaCO$_3$/liter	0 mg CaCO$_3$/liter
– Bicarbonate	1,520 mg CaCO$_3$/liter	2,100 mg CaCO$_3$/liter	94 mg CaCO$_3$/liter
• M.B.A.S.*	245 mg/liter	1,740 mg/liter	0.56 mg/liter
• COD	678 mg/liter	3,260 mg/liter	27.4 mg/liter
• BOD5	75 mg/liter	85 mg/liter	1.7 mg/liter
• Total Phosphorus	1.4 mg/liter	1.3 mg/liter	0.23 mg/liter
• Smoke Compound	2.1 mg/liter	8.3 mg/liter	1.7 mg/liter
• Appearance	Very little solid sediment in sample. Foams on shaking.	Very little solid sediment in sample. Foams on shaking.	No visible sediment, slightly hazy.
• pH	8.5	8.5	7.0

* Methylene Blue Active Substance (Ultrawet K).

Source: Case Consulting Laboratories, Inc.

TABLE 17.   PARTICULATE EMISSIONS MEASURED FROM EXHAUST STACKS

	Deep Fat and Rag Bale Fires	Bilge Fires
Concentration	0.245×10^{-6} lb/ft^3	0.050×10^{-6} lb/ft^3
Stack Air Flow	2,550 ft^3/min	1,948 ft^3/min
Total Running Time	4.05 hrs	4.27 hrs
Actual Scenario (Sampling) Time	1.08 hrs	1.14 hrs
Actual PKP Discharge Time	0.67 min = 0.01 hrs (40 sec)	0.93 min = 0.16 hrs (56 sec)
Emission Rate	0.0372 lb/hr	0.0059 lb/hr
Total Running Time Basis - Total Output	0.0372 (4.05) = 0.152 lb	0.0059 (4.27) = 0.025 lb
Actual PKP Discharge Time Basis	$\frac{0.0372}{0.01}$ = 3.7 lb/hr rate for 40 sec	$\frac{0.0059}{0.016}$ = 0.37 lb/hr rate for 56 sec
Estimated Discharge per Scenario (Based on Runs)	$\frac{(0.0372)(1.08)}{6}$ = 3.04 grams (deep fat fire only)	$\frac{(0.0059)(1.14)}{6}$ = 0.51 grams

Source: Case Consulting Laboratories, Inc.

NOTE: AFFF and PKP are used only as generic descriptors.
      Candidate substitutes were actually used in test runs
      (AFFF = 10% Ultrawet K, PKP = Sodium Bicarbonate).
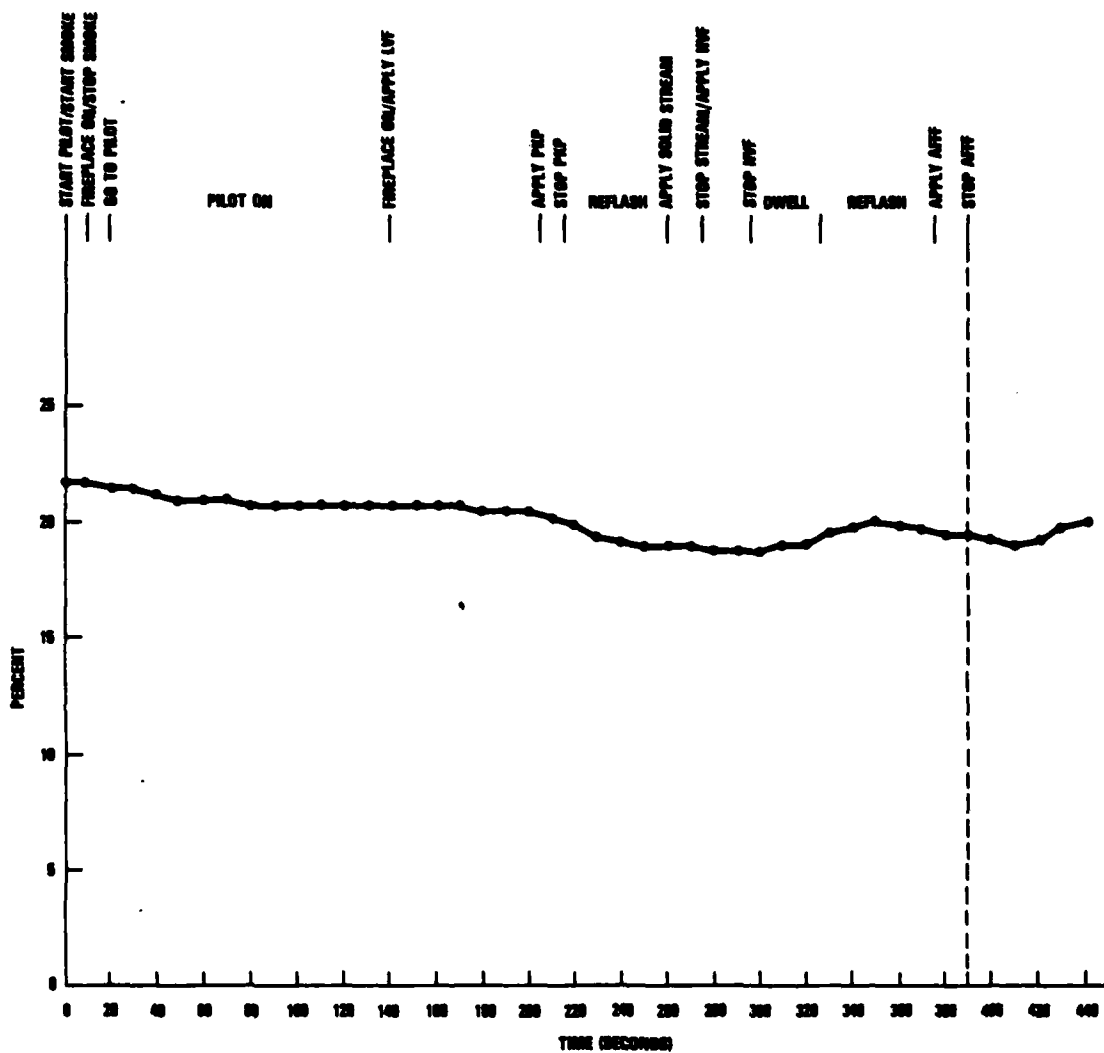
Figure 23.   LDQI Run 4 - O_2 Levels

98
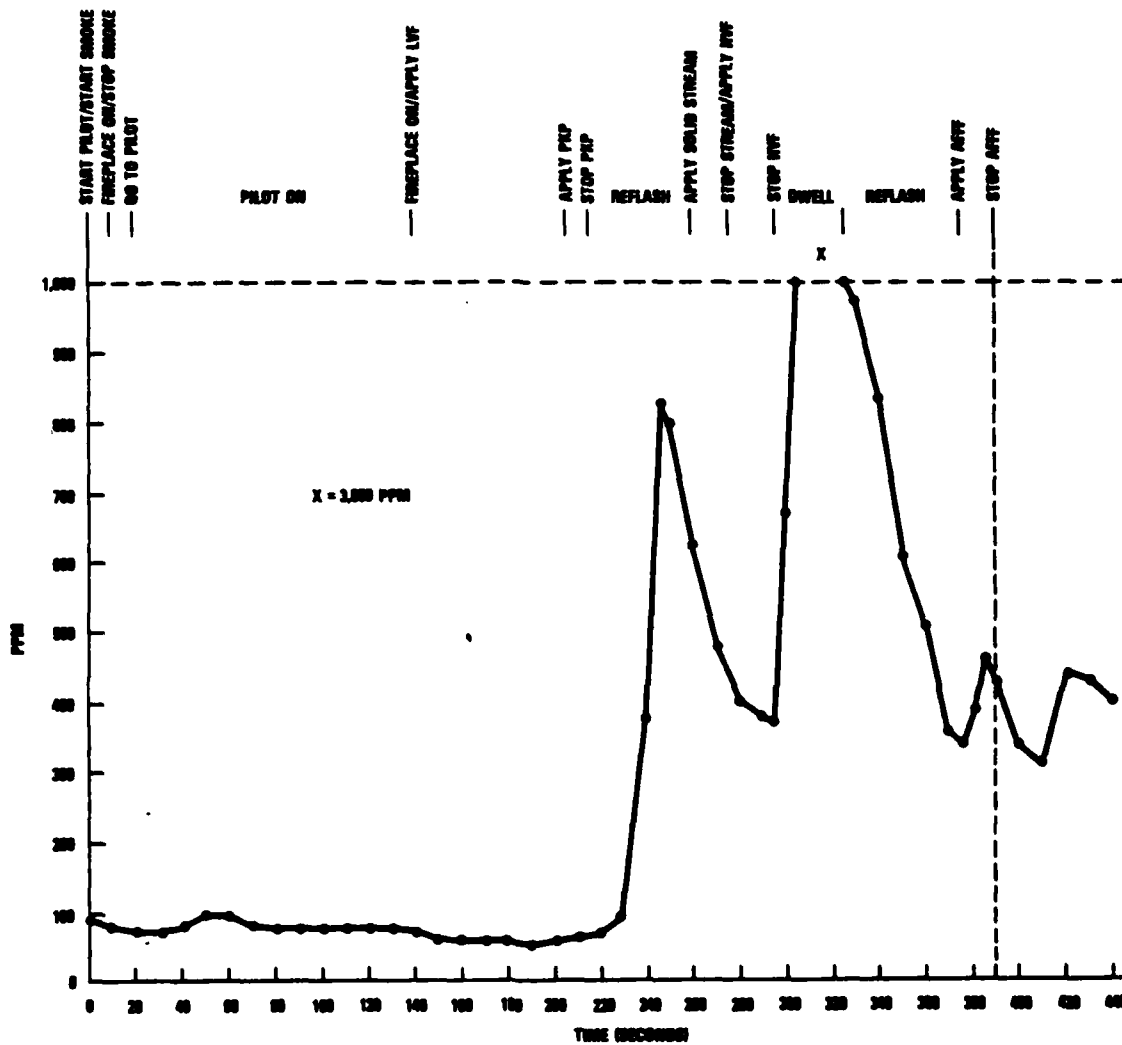
Figure 24. LDQI Run 4 - CO Levels

99
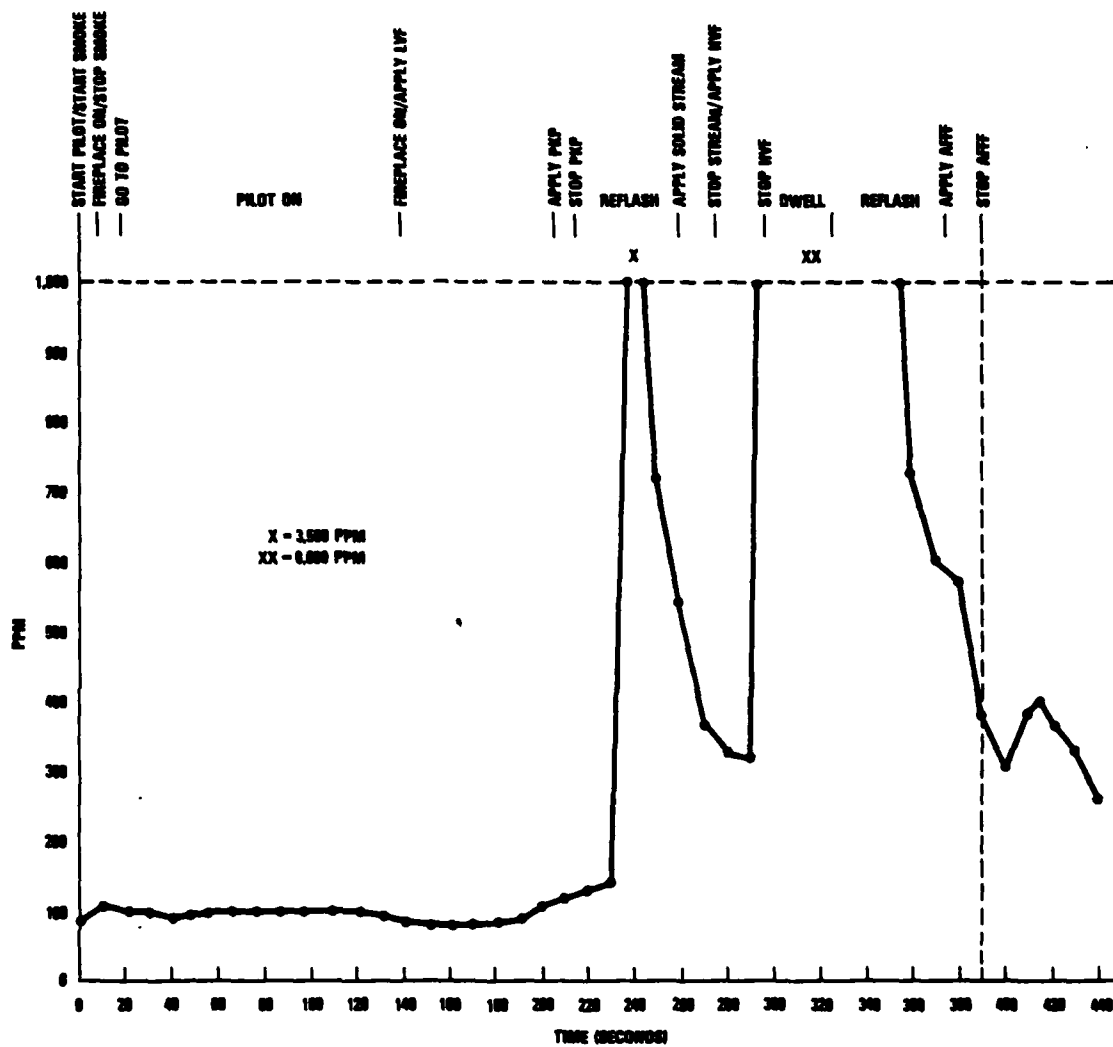
Figure 25. LDQI Run 4 - HC Levels
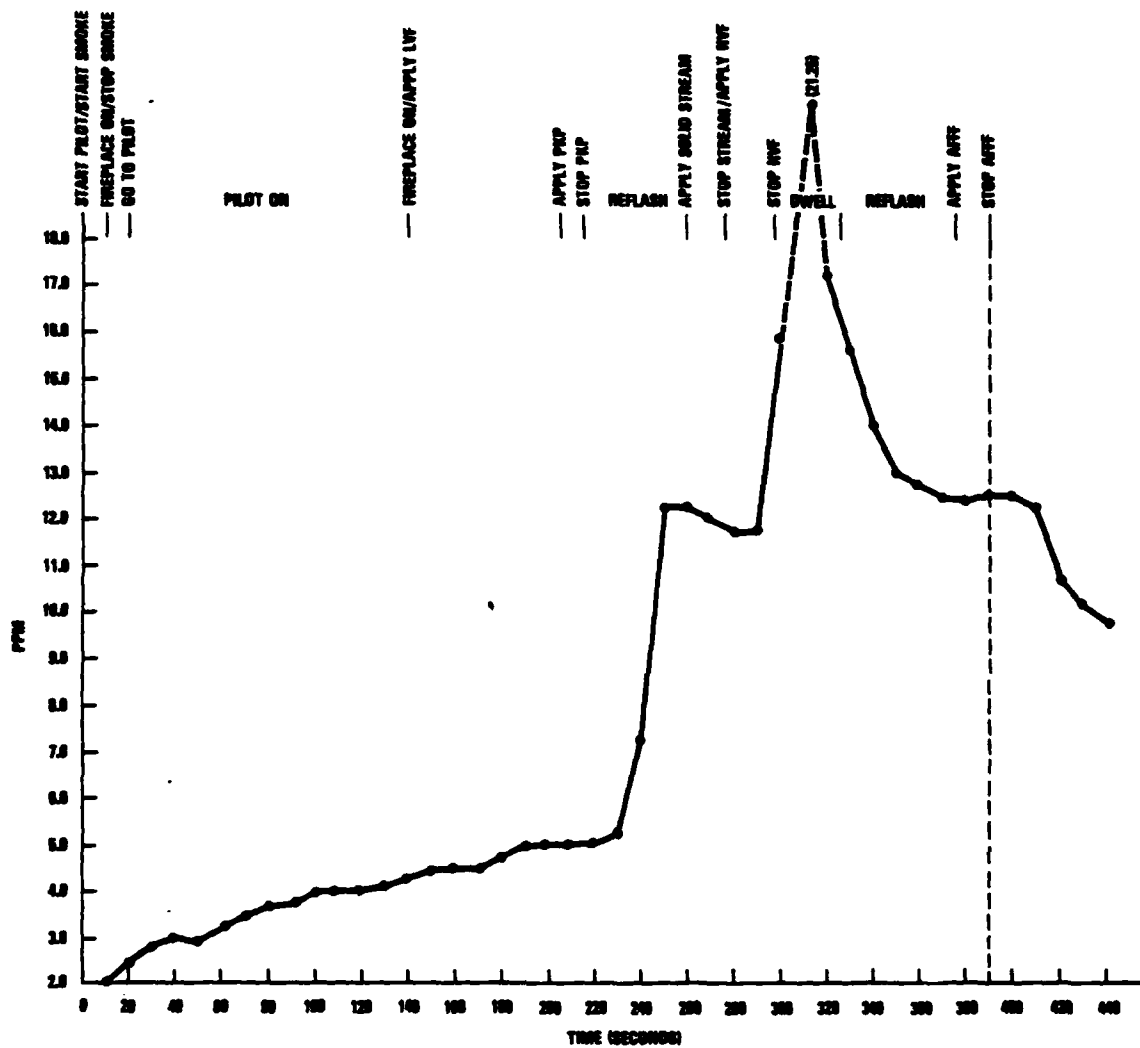
Figure 26.   LDQI Run 4 - NO$_x$ Levels

101
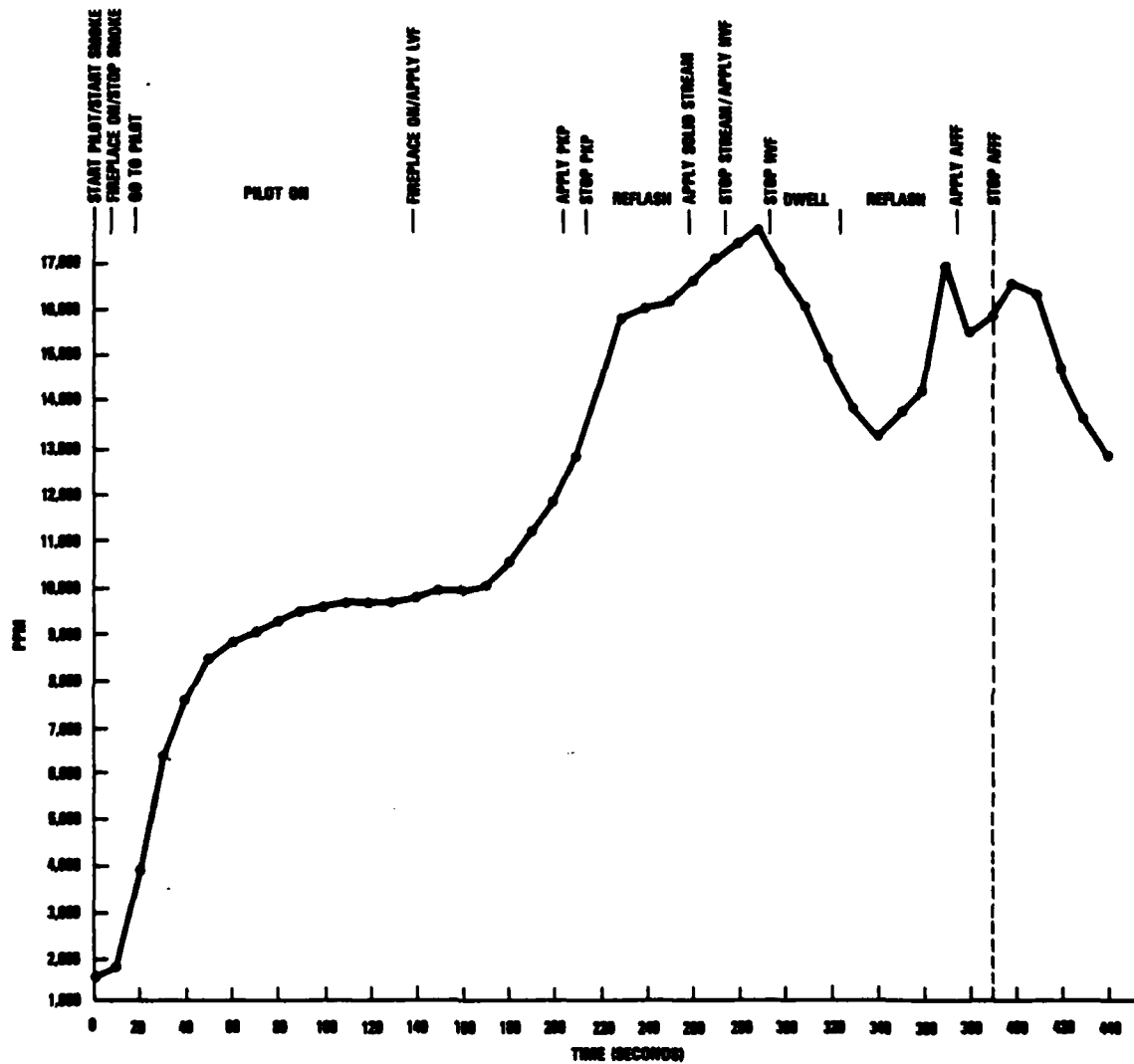
Figure 27. LDQI Run 4 - CO_2 Levels

102

Figure 28. UDQII Run 6 – O₂ Levels

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Figure 29. UDQII Run 6 – CO Levels

104
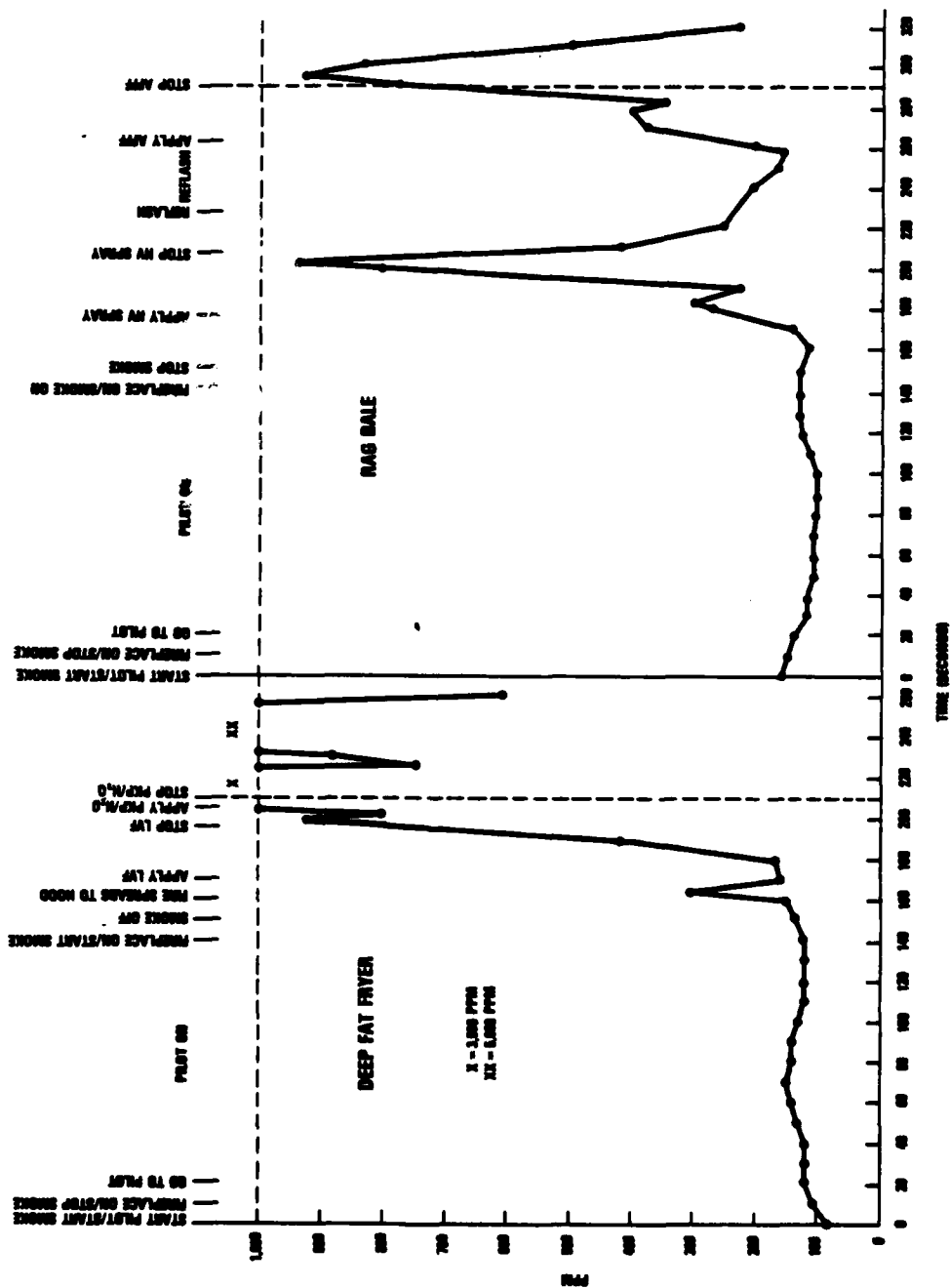
Figure 30. UDQII Run 6 - HC Levels
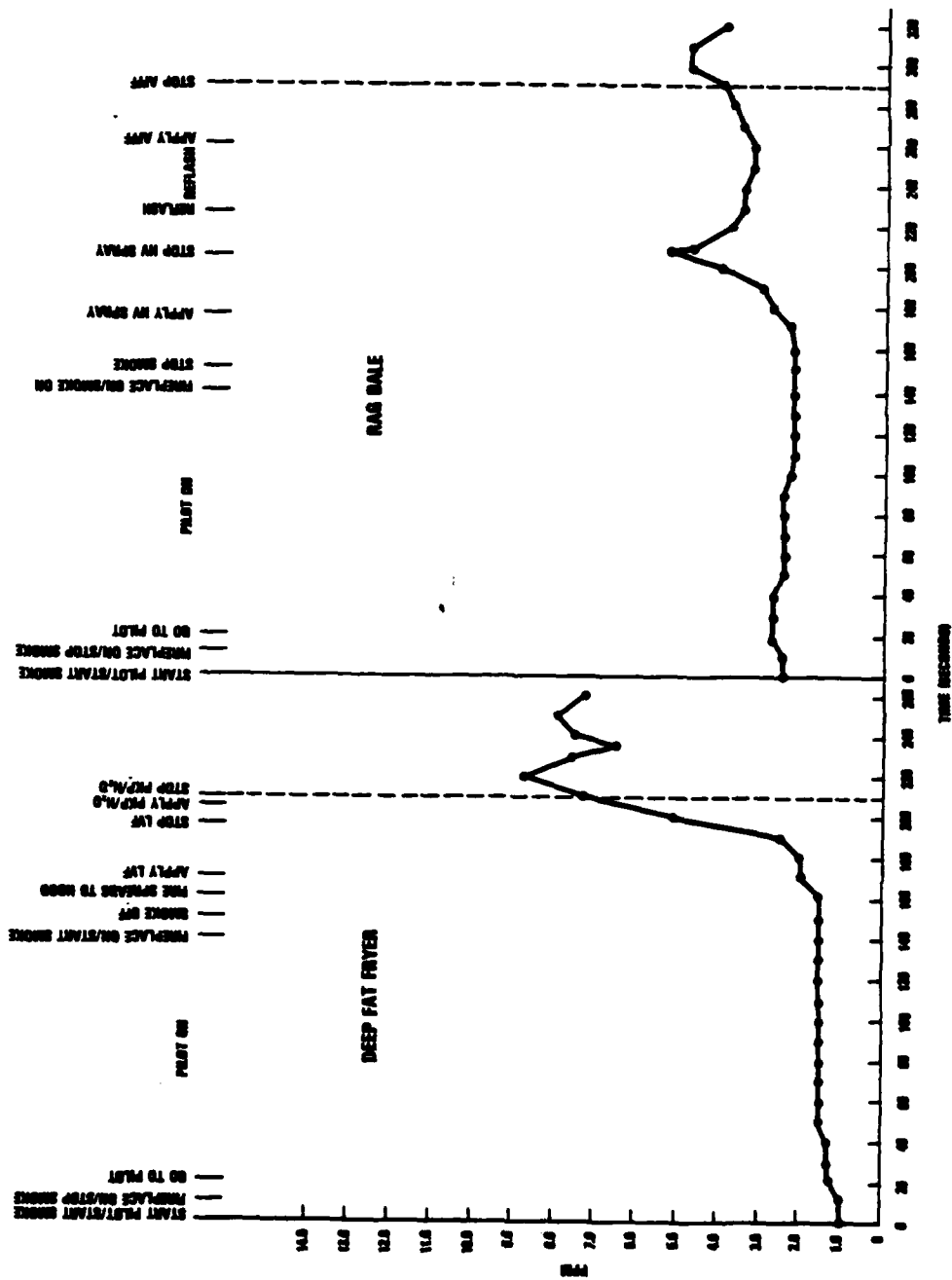
Figure 31. UDQII Run 6 - NO$_x$ Levels

106
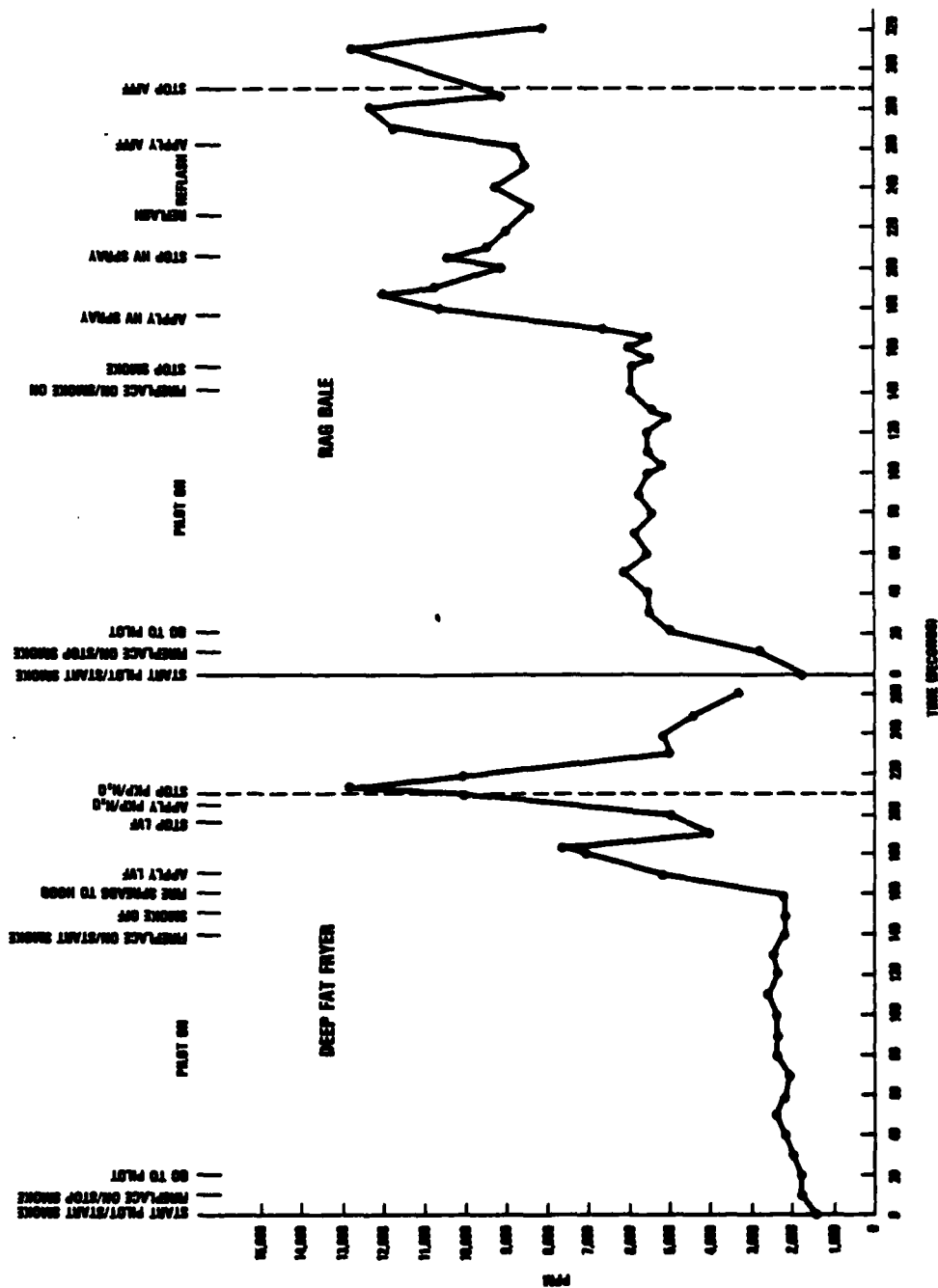
Figure 32. UDQII Run 6 - CO₂ Levels

TABLE 18. MAXIMUM GAS EMISSIONS IN TEST CELL*

Run	Deep Fat Fires				Bale Fires				Bilge Fires			
	O2	HC	CO	CO2	O2	HC	CO	CO2	O2	HC	CO	CO2
1	18.7%	0.3%	1.0%	2.7%	15.5%	0.2%	0.4%	4.3%	18.7%	0.3%	0.2%	0.2%
2	18.6	0.3	0.3	2.7	17.2	0.1	0.2	3.6	18.0	0.4	0.4	2.2
3	18.5	0.1	0.2	2.8	16.6	0.2	0.6	4.5	18.3	0.8	0.4	1.7
4	18.7	0.3	0.3	2.0	18.0	0.3	0.5	2.6	18.2	0.8	0.3	1.9
5	18.2	0.5	0.5	3.4	17.5	0.6	0.8	4.2	18.1	0.7	0.5	2.1
6	19.3	0.5	0.3	2.7	16.0	0.4	0.9	5.7	18.5	0.4	0.2	1.5
7	18.7	0.4	0.7	3.1	17.7	0.3	0.7	4.3	—————Cancelled—————			
8	19.2	0.5	0.2	3.4	18.0	0.3	0.5	4.0	—————Cancelled—————			
9									18.0	0.5	0.4	2.5
10									17.7	0.4	0.3	2.3

* Minimum for oxygen concentrations.

Source: Case Consulting Laboratories, Inc.

The values for these minimum oxygen concentrations and maximum gaseous concentrations are based upon the backup monitoring equipment which, in the case of the rag bale scenario, had its sensors in closer proximity to the fire than those of the installed monitors.

Gas flow into the facility was also graphed and is shown in Figures 33 and 34 and in Appendix F.

3.5.3 Simulated smoke concentration. The analysis of the two cumulative 1-minute smoke samples taken during onsite testing revealed TAP concentrations of 940 and 1,100 micrograms per liter. The average smoke concentration in the facility after initiation of the smoke generator (at an estimated consumption rate of 1 liter TAP per minute) was, therefore, estimated to be 1,020 micrograms per liter.

3.5.4 Temperature. Interior-measured temperatures did not exceed 660°F, which occurred in LDQI (bilge fire) Run 10 at a location directly above the flame. No temperatures more than 340°F were recorded at other locations during the bilge fire. The deep fat fryer/rag bale fires were less energetic with no temperatures greater than one peak of 400°F. The maximum temperatures recorded during each run are presented in Tables 19 and 20.

Temperatures returned to baseline within 2.5 minutes maximum following completion of the run for deep fat fryer/rag bale fires. Maximum cycle time for bilge fire temperatures to return to baseline was 18.7 minutes occurring in Run 10. These results are shown in Table 21.

The wet bulb and globe thermometer measurements, as shown in Table 22, did not exceed 168°F for the bilge fire and 90°F for the deep fat/rag bale fire.

3.5.5 Noise. The noise measurements performed during smoke-generator operation at a distance of 3 feet from the generator are presented in Figure 35. This figure shows A-weighted sound levels and plots of octave band levels.

At a distance of 10 feet from the smoke generator, the A-weighted sound pressure level was determined to be 96 dBA. At a distance of 50 feet, the sound pressure level was 87 dBA.
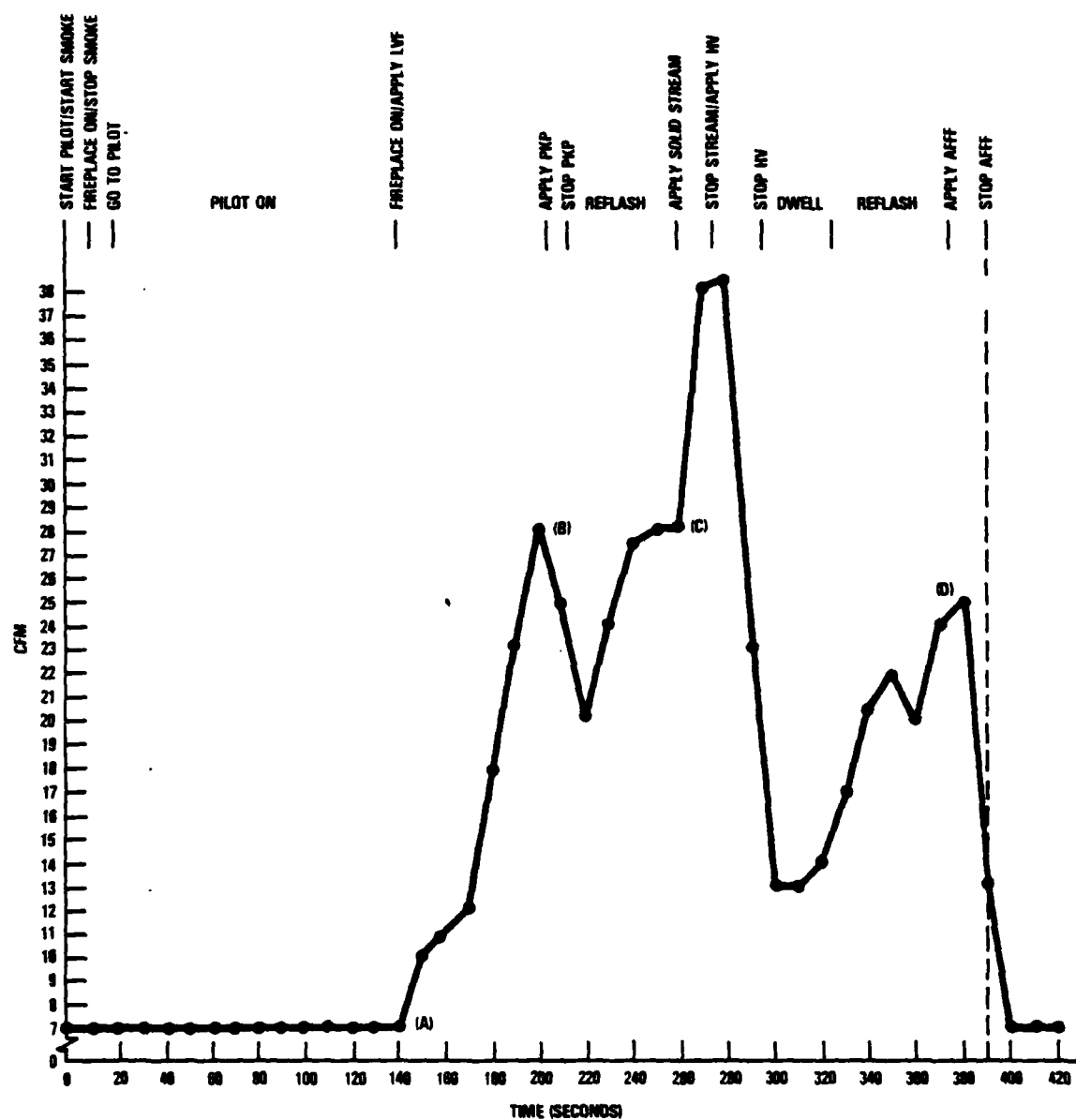
Figure 33. LDQI Run 4 - Gas Flow

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Figure 34. UDQII Run 6 - Gas Flow

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TABLE 19. MAXIMUM TEMPERATURES RECORDED - LDQI

Location of Thermocouples

Run	1	2	3	4	5	6	7	8	9
1	180 (150 sec)	120	100	100	170 (193 sec, 275 sec)	100	280 (150 sec, 260 sec)	130	130
2[a]	300 (300 sec)	>2,000[b] (160 sec)	100	100	280 (300 sec)	110	540 (340 sec)	180	180
3	220 (210 sec)	1,300[b] (50 sec)	100	100	150	240 (410 sec)	460 (215 sec, 405 sec)	150	150
4	210 (375 sec)	180 (205 sec)	100	100	250 (275 sec)	100	510 (260 sec)	100	150 (200 sec)
5	220 (395 sec)	155 (212 sec)	100	100	240 (295 sec)	100	600 (275 sec, 395 sec)	150 (205 sec)	
6[c]	190 (180 sec)	160 (160 sec)	100	100	220 (275 sec)	120	430 (240 sec)	100	
7					----Aborted----				
8					----Aborted----				
9	270 (405 sec)	200 (205 sec)	100	100	240 (405 sec)	120	590 (375 sec)	100	170 (250 sec)
10	340 (295 sec)	270 (295 sec)	100	100	300 (305 sec)	160 (240 sec)	640 (260 sec)	100	200 (375 sec)

NOTE: Maximum flame temperature: # 5 1,635°F   Full flame: 1,490°F
                                  # 4 1,536°F

[a] Water turned off at 225 seconds.
[b] Thermocouple shorted with water.
[c] Two pilots out on this run.

Source: Case Consulting Laboratories, Inc.

TABLE 20. MAXIMUM TEMPERATURES RECORDED - UDQII

Location of Thermocouples

Run	1	2	3	4	5	6
1	100	200 (390 sec)	100	100	150 (360 sec)	210 (340 sec)
2	100	170 (240 sec)	100	100	115 (220 sec)	190 (260 sec)
3	100	180 (290 sec)	100	100	130 (175 sec)	190 (260 sec)
4	100-110	170 (225 sec)	100-110	100-110	130 (205 sec)	200 (310 sec)
5	100-110	190 (330 sec)	100-110	100-110	130 (160 sec)	220 (310 sec)
6	100-110	170 (205 sec)	100-110	100-110	130 (310 sec)	220 (330 sec)
7	100-110	180 (205 sec)	100-110	100-110	120 (150 sec)	200 (290 sec)
8	100-110	400 (250 sec)	100-110	100-110	120 (370 sec)	240 (250 sec)

NOTE: Maximum flame temperature:

Rag bale	Pilot 1,400°F	Full flame 1,340°F
Deep fat fryer	Pilot 1,420°F	Full flame 1,420°F
Fat fryer hood	Pilot 2,010°F	Full flame 1,425°F

Shouds taken off #2 and #6 for Run 8.

All maximum temperatures reached during rag bale scenario.

Source: Case Consulting Laboratories, Inc.

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TABLE 21.   TEMPERATURE CYCLE TIME

Run No.	Type Fire	Temperature Cycle Time (Seconds)	Comment
1	Fat	150	—
1	Bale	520	—
2	Fat	90	—
2	Bale	550	—
3	Fat	150	—
3	Bale	750	—
4	Fat	—	Temperature rise too small to discern cycle
4	Bale	780	—
5	Fat	—	Temperature rise too small to discern cycle
5	Bale	780	—
6	Fat	—	Temperature rise too small to discern cycle
6	Bale	780	—
7	Fat	—	Temperature rise too small to discern cycle
7	Bale	800	—
8	Fat	140	—
8	Bale	570	—
1	Bilge	430	Run not completed
2	Bilge	1050	—
3	Bilge	960	—
4	Bilge	980	—
5	Bilge	750	—
6	Bilge	1020	—
7	Bilge	—	Run aborted
8	Bilge	—	Run aborted
9	Bilge	720	—
10	Bilge	1120	—

Source: Case Consulting Laboratories, Inc.

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TABLE 22.   WET BULB AND GLOBE THERMOMETER READINGS

Run	Deep Fat/Bale Fires UDQ2		Bilge Fires LDQ1	
	W.B.	Globe	W.B.	Globe
1	82°F	85°F	104°F	92°F (1)
2	86	90	-	-
3	-	-	123	105
4	86	85	125	112
5	-	-	120	105
6	86	85	116	101 (2)
7	89	85	-	-
8			-	-
9			123	116
10			129	168 (3)

Notes:

(1)   Metal shield covering thermometers removed after this run.

(2)   Two burners out.

(3)   Low velocity fog not used.

Source: Case Consulting Laboratories, Inc.

Figure 35. Noise Levels of Smoke Generator
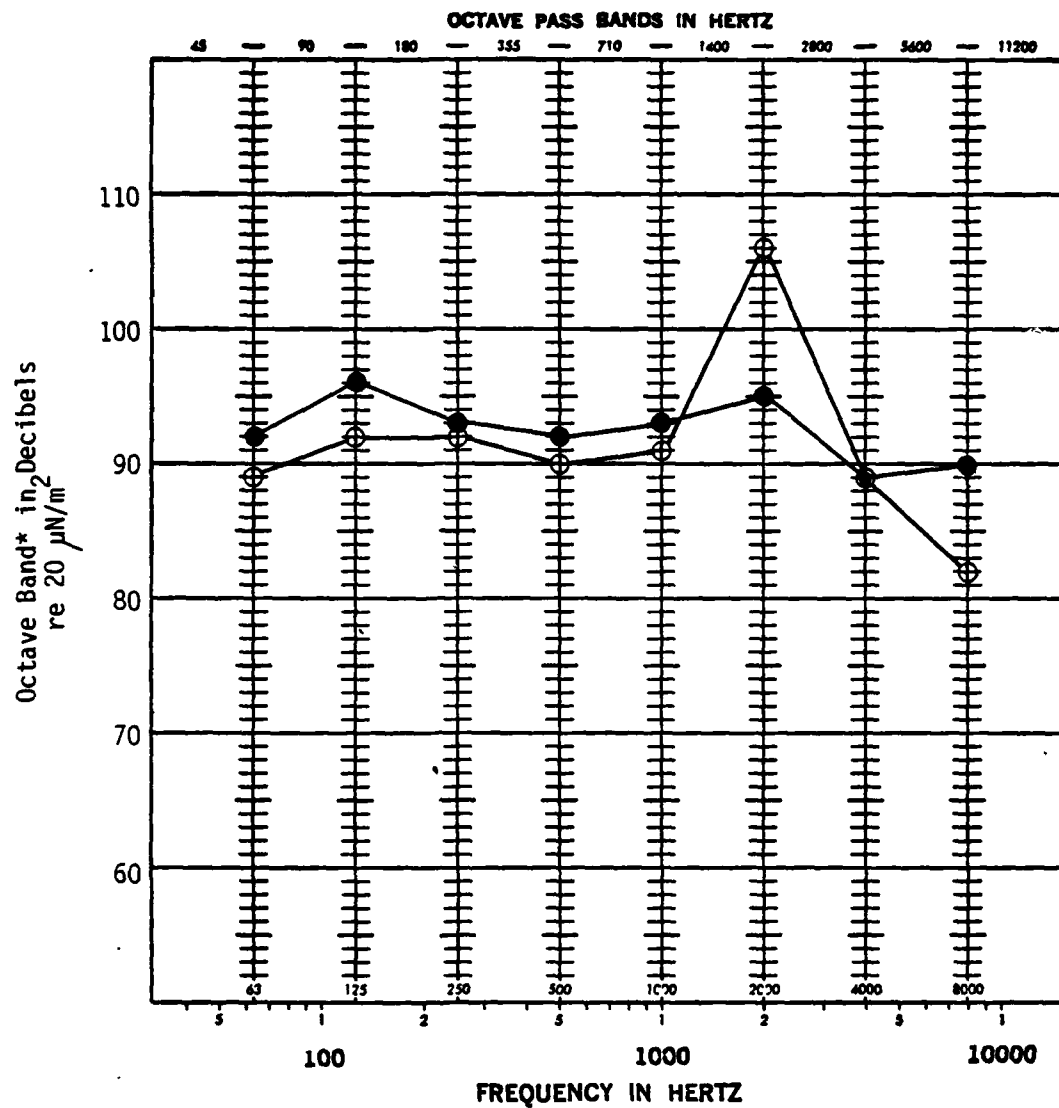
Burner On, Burner Temp. 800°F, Engine RPM 2,500

Burner Off, Engine RPM 2,800

A-Weighted Sound Level:

96 dBA at 10 feet
87 dBA at 50 feet

*Octave band measurements made at a distance of 3 feet from the compressor end of the fogger.

Figure 35. Noise Levels of Smoke Generator

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4. ASSESSMENT OF ENVIRONMENTAL CONSIDERATIONS

Based on the information collected during the onsite
testing period, interviews with regulatory experts in
government and industry, and analysis of the regulatory
constraints outlined in our Phase I report (see Appendix A), an
assessment has been made of the environmental, health, and
safety aspects of the modified 19F1. This assessment,
presented in this section, covers the following areas:

- Environmental considerations

- Health effects

- Safety factors

- Heat/operating temperatures

- Relation of operating parameters to scenario
  activities.

4.1 Environmental considerations. This section presents
an environmental assessment of the data collected during onsite
testing as they relate to applicable federal, state, and local
environmental standards. ‘The assessment is divided into the
following sections:

- Air emissions
- Wastewater
- Solid waste
- Noise
- Meeting environmental standards.

The identification and discussion of the environmental,
health, and safety constraints presented in the final Phase I
report are presented in Appendix A of this report.

4.1.1 Air emissions. The air emissions data outlined in
Section 3.5 has been evaluated in terms of its relation to the
current environmental standards. This evaluation is presented
in terms of particulate matter and gases.

4.1.1.1 Particulate matter. The results of the stack
emission sampling taken during the onsite sampling program
reveal that the proposed facility will emit a maximum of 0.0372
pounds of particulate matter averaged over 1 hour from the
functional half of the facility. Because there will be
eventually two functioning halves of the facility, both of
which may operate simultaneously, the maximum emission rate for
particulate matter will be approximately 0.0744 pounds/hour.

Since it is not clear how a regulatory agency will characterize the 19Fl AFFT, some possible hypotheses can be postulated. If the facility were considered an industrial batch-processing plant, the allowable emission rate corresponding to the process rate may be used to determine the emission-control requirements. The process weight, in this case, would be the amount of sodium bicarbonate injected into the building, or approximately 240 pounds/hour for both halves. Using Table 23, the maximum allowable emission rate for the facility would be 0.893 pounds/hour. The contribution by weight of the triarylphosphate smoke is negligible in relation to the bicarbonate.

Because the estimated maximum particulate matter emission rate from the proposed facility is much lower than the allowable emission rate, ordinarily, there would be no particulate emission control requirement for the facility. However, it is estimated that the facility will emit a visible plume of triarylphosphate for at least 1 minute during each training scenario. With an estimated eight training scenarios per hour for both halves of the facility, a visible plume would be emitted from the facility for about 8 minutes per hour. This may cause a violation of the opacity standard in several states (see Table 24). As a result, some form of particulate emission control may be needed if the regulatory agency strictly adheres to this opacity standard. An exemption is usually made for a steam plume because it does not add particulate matter to the atmosphere. The extent of control would be negotiated with the regulatory body. However, a typical control for this type of emission would probably use a two-stage electrostatic precipitator. Mechanical controls (i.e., cyclones and inertial impactors) could be effective if the aerosol characteristics of the plume permitted their use.

The following sections provide a summary of Connecticut regulations that are typical of state emission-control requirements for carbon monoxide, nitrogen oxides, total suspended particulates, and volatile organic compounds emissions. Connecticut has been used as the model since it has defined and documented standards that permit ready comparison to actual values. Other states prefer reviewing and judging emissions on a case-by-case basis. Table 25 summarizes the ambient air quality standards relevant to the states with proposed fire-fighting sites.

4.1.1.1.1 Control of carbon monoxide (CO). According to Connecticut regulations for the emissions of CO from steel or petroleum processing facilities, the waste gas containing CO must be incinerated in a direct flame afterburner, boiler, or equivalent device at a temperature of 1,300°F for a period of not less than 0.3 second.

TABLE 23.   CONNECTICUT MAXIMUM ALLOWABLE EMISSION RATES

Process Weight Rate (lbs/hr)	Emission Rate (lbs/hr)	Process Weight Rate (lbs/hr)	Emission Rate (lbs/hr)
50	0.36	60,000	29.60
100	0.55	80,000	31.19
500	1.53	120,000	33.28
1,000	2.25	160,000	34.85
5,000	6.34	200,000	36.11
10,000	9.73	400,000	40.35
20,000	14.99	1,000,000	46.72

TABLE 24. VISIBLE EMISSION STANDARDS

State	Opacity Standard	Exemptions for Fire-Fighting Training
California (San Diego)	Not to exceed 20 percent any time.	None.
Connecticut	Not to exceed 20 percent, except for 5 minutes in any 1 hour up to 40 percent opacity is allowed.	Fire-fighting training under open-burning conditions is exempted.
Florida	Not to exceed 20 percent.	None.
Hawaii	Not to exceed 40 percent, except for 3 minutes in any 1 hour up to 60 percent is allowed.	None.
Illinois	Not to exceed 20 percent, except for 3 minutes in any 1 hour up to 40 percent is allowed.[1] Not to exceed 30 percent, except for 8 minutes in any 1 hour up to 60 percent is allowed.[2]	None.
Rhode Island	Not to exceed 20 percent, except for 3 minutes in any 1 hour.	None.
South Carolina	Not to exceed 20 percent, except for 6 minutes in any 1 hour but no more than 24 minutes per day up to 60 percent is allowed.	Fire-fighting training exempted from open-burning regulation.
Virginia	Not to exceed 20 percent, except for two 6-minute periods in any 1 hour.	Fire-fighting training exempted from open-burning regulation.
Washington	Not to exceed 20 percent, except for 15 minutes in any 8-hour period.	None.

[1] New fuel combustion sources with actual heat input > 250 million Btu/hr.

[2] All other sources.

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TABLE 25. AMBIENT AIR QUALITY STANDARDS

	Carbon Monoxide (mg/m³)		Hydrocarbons (μg/m³)		Lead (μg/m³)		Ozone (μg/m³)		Nitrogen Dioxide (μg/m³)		Sulfur Dioxide (μg/m³)			Total Suspended Particulates (μg/m³)	
Federal[1]	10	8 hrs.	160	3 hrs.	1.5	3 mos.	235	1 hr.	100	annual	80	annual	75	annual
	40	1 hr.									365	24 hrs.	260	24 hrs.
											1,300	3 hrs.		
California[2]	10	12 hrs.	Federal		1.5	30 days	200	1 hr.	500	1 hr.	0.05 ppm	24 hrs.	60	annual
	40	1 hr.									0.5 ppm	1 hr.	100	24 hrs.
Florida	Federal		Federal		Federal		Federal		Federal		60	annual	60	annual
											260	24 hrs.	150	24 hrs.
											1,300	3 hrs.		
Hawaii	5	8 hrs.	100	3 hrs.	Federal		100	1 hr.	70	annual	20	annual	55	annual
	10	1 hr.							150	1 hr.	80	24 hrs.	150	24 hrs.
											400	3 hrs.		
Illinois[3]	Federal		Federal		Federal		Federal		Federal		Federal		73	annual
													260	24 hrs.
South Carolina[4]	Federal		Federal		Federal		Federal		Federal		Federal		60	annual
													250	24 hrs.
Washington[5]	Federal		Federal		Federal		0.08 ppm 1 hr.		Federal		0.02 ppm	annual	150	24 hrs.
											0.1 ppm	24 hrs.		
											0.4 ppm	1 hr.		
Japan[6]	10 ppm	24 hrs.							0.04-0.06 ppm	24 hrs.	0.04 ppm	24 hrs.	100	24 hrs.
	20 ppm	8 hrs.									0.1 ppm	1 hr.	200	1 hr.

[1] Connecticut, Rhode Island, and Virginia have adopted the federal standards.
[2] California also has the following standards: H_2S, 0.03 ppm (1 hr.); sulfates, 25 mg/m³ (24 hrs.).
[3] Illinois also has the following standard: photochemical oxidants, 160 μg/m³ (1 hr.)
[4] South Carolina also has the following standards: gaseous fluorides, 0.8 ppm (30 days), 1.6 ppm (7 days), 2.9 ppm (24 hrs.), and 3.7 ppm (12 hrs.).
[5] Washington also has the following standards: fluorides (as HF), 2.9 μg/m³ (24 hrs.), 1.7 μg/m³ (7 days), and 0.84 μg/m³ (30 days).
[6] Japan also has the following standard: photochemical oxidants, 0.06 ppm (1 hr.).
[7] Rhode Island also has the following standard: H_2S, 0.01 ppm (1 hr.).

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4.1.1.1.2 Control of nitrogen oxides (NO_x). For gas-fired fuel burning equipment, the Connecticut regulations stipulate that the NO_x emissions calculated as nitrogen dioxide must not exceed 0.2 pound per million Btu of heat input. This requirement applies to all equipment with a maximum capacity rating above 250 million Btu per hour. For equipment rated between 5 and 250 million Btu/hour, these regulations shall apply unless the Commissioner is satisfied that it is not technically or economically feasible for a unit of the size considered.

4.1.1.1.3 Control of particulate matter. Connecticut has separate sets of emission standards for particulate matter emissions from fuel-burning equipment and process industries. For fuel-burning equipment, no person shall cause or permit the emission from fuel-burning equipment of particulate matter in excess of 0.20 pound per million Btu of heat input for existing sources and 0.10 pound per million Btu of heat input for new sources.

For process industries, the emission of particulate matter must not exceed the amount shown in Table 23 for the process weight allocated to the source.

For the purpose of this regulation, process weight per hour is the total weight of all materials introduced into any specific process that may cause any emission of particulate matter. Solid fuels charged will be considered as part of the process weight, but liquid and gaseous fuels and combustion air will not. For a cyclical or batch operation, the process weight per hour will be derived by dividing the total process weight by the number of hours in one complete operation from the beginning of any given process to its completion, excluding any time during which the equipment is idle. For a continuous operation, the process weight per hour will be derived by dividing the process weight for a typical period of time by the length of that period of time.

4.1.1.1.4 Control of volatile organic compounds (VOC). Connecticut has established stringent emission limitations on photochemically reactive VOC and less stringent limitations on nonphotochemically reactive VOC. According to the regulations, the discharge of photochemical reactive organic compounds is generally limited to 40 pounds per day or 8 pounds per hour unless the discharge has been reduced by at least 85 percent. For nonphotochemically reactive species, the general limitation is 800 pounds per day or 160 pounds per hour unless the discharge has been reduced by at least 85 percent. Photochemically reactive organic compounds are defined as follows:

- Group R1: Any hydrocarbons, alcohols, aldehydes, esters, ethers, or ketones having an olefinic or cyclo-olefinic type of unsaturation

- Group R2: Any aromatic compounds with eight or more carbon atoms to the molecule except ethylbenzene, phenyl acetate, and methyl benzoate

- Group R3: Any ketones having branched hydrocarbon structures, and ethylbenzene, trichloroethylene, and toluene.

Any solvent mixture will be considered photochemically reactive if the composition of such mixture exceeds any of the following limits by volume:

- 5 percent of any combination of chemical compounds in Group R1

- 8 percent of any combination of chemical compounds in Group R2

- 20 percent of any combination of chemical compounds in Group R3

- 20 percent of any combination of chemical compounds in Groups R1, R2, and R3.

Whenever any organic solvent or any constituent of any organic solvent may be classified from its chemical structure into more than one of these groups of organic compounds, it will be considered a member of the most reactive chemical group, which is that group having the least allowable percent of the total volume of solvents.

Any solvent not classified above and any solvent mixture that does not exceed any of the above limits will be considered photochemically nonreactive.

4.1.1.2 Gases. Since high CO levels (up to 10,000 ppm) were recorded for short periods of time, an assessment of the impact on ambient CO levels was performed. The maximum CO concentration in the stack gases was observed to be 1 percent for a few seconds during a training session. The concentration then consistently dropped back to lower levels during the remaining period of the scenario. Nevertheless, the maximum concentration was assumed to prevail during the entire session to determine the air quality impact under the worst case. Assuming a wind speed of 2 meters per second and atmospheric stability Class B (as defined by EPA), the maximum ground-level

CO concentration was estimated to be 1 ppm over 1 hour and 0.07 ppm over 8 hours. Both of these values are considerably lower than the corresponding ambient CO level of 35 ppm for 1 hour and 9 ppm for 8 hours.

Based on the test data for hydrocarbons and oxides of nitrogen levels in the stack gases, the emissions of these two pollutants will be insignificant - less than 1 ton per year. Thus, there would be no need to control these emissions.

The Japanese emission standards, as cited in our original report, are specific to certain types of operation. The proposed AFFT facility does not fall under any of the operational categories presently set forth by the Japanese Environment Agency. Therefore, such a facility located in Japan would most likely be regulated on an individual basis.

4.1.2 Wastewater. Most of the sewage treatment plants to which the proposed AFFT facilities will be discharging wastewaters have industrial wastewater discharge standards. These standards are designed to prevent industrial effluents from interfering with the operation of the plants or from passing through the plant without adequate treatment. Table 26 summarizes the relevant standards expected to apply to the AFFT facilities.

The results of the chemical analyses of wastewater effluents of the prototype AFFT facility, as described in Section 3.5, serve as a basis for determining whether AFFT facility discharges will meet the discharge standards. A comparison of the results of the analyses of the LDQI and UDQII prototype effluents with the discharge standards from the seven AFFT sites reveals only one apparent out-of-compliance situation. The BOD standard of 50 mg/l for San Diego is exceeded by the BOD concentrations in both wastestreams: 75 mg/l for the Lower Deck Quadrant I (LDQI) and 85 mg/l for the Upper Deck Quadrant II (UDQII). All other parameters are within the limits established by the standards at each site. However, the BOD values observed were considered to be artificially depressed for the reasons outlined later in this section, and thus noncompliance may occur at other sites. In addition, the LDQI stream's suspended solids concentration is just within the San Diego standard (42 mg/l as compared with 50 mg/l). Thus, a variation of 20 percent in its effluent solids composition would cause the standard to be exceeded.

Although the pH value of each wastestream is within the established standards, the values are near the upper end of the allowed range due to the high alkalinity of the wastewaters. The pH values for LDQI and UDQII are both 8.5, with the

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TABLE 26. POTW INDUSTRIAL EFFLUENT STANDARDS POTENTIALLY
APPLICABLE TO AFFT

AFFT Sites	pH	BOD[1]	Oil and Grease	Ammonia Nitrogen	Suspended Solids
Charleston, SC	6.5-8.5	300 ppm	100 ppm		300 ppm
Great Lakes, IL	6.0-9.0	300 ppm	75 ppm	50 ppm	350 ppm
Orlando, FL	6.5-9.5	300 mg/l	100 mg/l		300 mg/l
Norfolk, VA	6.0-9.0	250 mg/l	100 mg/l		250 mg/l
Newport, RI	≤ 10.0	230 mg/l	25 mg/l[2]		285 mg/l
New London, CT	6.5-9.0		100 mg/l		100 mg/l
San Diego, CA	5.0-9.0	50 mg/l	40 ppm weekly avg.; 25 ppm monthly avg.	325 ppm	50 mg/l

[1] Biochemical oxygen demand.

[2] Floatable oil, fat, or grease not permitted.

Note: Additional limitations may be set by individual POTWs on such parameters as
COD (chemical oxygen demand) and surfactants.

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corresponding upper value of the standards ranging from 8.5 for Charleston, South Carolina, to 10 for Newport, Rhode Island. Samples containing carbonate and bicarbonate alkalinity in the proportions exhibited by the LDQI and the UDQII effluents typically have pH values of 8.3 or greater. Therefore, it is possible that the pH standard at some sites, particularly in Charleston, could also be exceeded with a slight variation in the pH of the AFFT wastestreams. On the other hand, the high concentrations of bicarbonate and carbonate ions provide effective buffering capacity of the effluent to changes in pH, thus wide variations in pH are not anticipated.

In addition to the effluent characteristics addressed by the standards summarized in Table 26, two other characteristics of the AFFT wastewaters that are discussed in this section regarding compatibility with downstream sewage treatment systems are flow variations and surfactant concentrations. As wastewater is generated only during the fire fighter training exercise, flow rates are extremely cyclic. They vary from zero during nontraining periods to peak flows occurring during the exercise. The efficiency and reliability of a downstream sewage treatment plant may be adversely affected by these sudden flow variations, depending on the size of the facility in relation to the AFFT effluent volumes. In particular, the biological treatment portion of a relatively small sewage treatment plant may have difficulty handling the high-strength organic surfactant wastewaters of short duration.

The anionic surfactant, Ultrawet K, is present in relatively high concentrations, particularly in the UDQII wastestream. According to available information (both the manufacturer's and available engineering data), this material is readily biodegradable. However, the corresponding BOD values for each wastestream may have been somewhat depressed. The reason for this is because the "seeding" organisms used in a standard 5-day BOD test of the samples may not have the specific organisms that could use the synthetic organic matter present. Thus, the BOD of the samples may be underestimated. Due to the severe time constraints of the testing program, acclimatized "seeding" organisms could not be cultured (a process requiring up to two months) prior to determining the standard biochemical oxygen demand, thus resulting in an unexpected disparity with the COD. This disparity could be interpreted as the presence of a toxin; however, with the knowledge of the materials present in the sample, it should be considered a result of an analytical phenomenon rather than an indication of nonbiodegradability. There are currently over 300 million pounds of this surfactant being produced annually with the majority ultimately entering wastewater effluent streams. In addition, the inherent chemical stability of this

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material minimizes the possibility of it changing its chemical properties during use. Specific bench-scale treatability studies would be indicated in cases where surfactant levels are a concern. These tests would involve small-scale laboratory evaluations of comparable wastewater effluents to determine the optimal treatability requirements prior to construction of a full-scale treatment facility. This is a typical sanitary engineering practice in situations such as these.

The use of acclimated seed organisms in the BOD test may show the BOD of AFFT effluent to be at levels that may exceed the specific allowable industrial waste discharge standards for BOD. Due to the inherent aquatic toxicity of surfactants, direct discharge would never be acceptable; biodegradation is always necessary prior to discharging into natural waters.

Another concern raised by the presence of the Ultrawet K surfactant in AFFT effluents is its potential to cause foaming at the sewage treatment plant. Again, depending on the size of the plant, a facility that incorporates aeration as part of the treatment process may experience foaming at the aeration tank, which, in turn, may lead to upsets in treatment performance. This matter can be addressed at each location if it arises.

Based on this assessment, pretreatment of some AFFT effluents may be necessary prior to discharge to the respective sewage treatment systems serving each site. A discussion of possible approaches that would satisfy pretreatment requirements is provided in Section 5.4.2.

4.1.3 Solid waste. As outlined in our Phase I report, the spent oxygen-breathing apparatus (OBA) canisters represent the primary source of solid waste connected with the 19F1 trainer. According to the Mine Safety Appliances Company (MSA), the OBA canisters are neutralized by punching them with holes and soaking them in water. Based on additional information supplied by MSA and on data taken from the military specification pertinent to the OBA (MIL-0-15633C and MIL-C-17671C), a spent OBA canister, after soaking in water, will release the following compounds:

- KOH, 448 g
- NaOH, 193 g
- NaCl, 37.8 g
- KCl, 0.57 g
- $Ba(OH)_2$, 3.5 g
- Fiberglass, 4 g
- Iron oxides, 8.2 g
- Nickel, 0.075 g
- Titanium, 0.050 g
- Infusiorial earth, 0.012 g.

The last five items will be suspended solids. The empty canisters may be disposed of with ordinary solid waste. The

remaining solution can be discharged into a POTW, provided it is pH controlled.

Biological solids might be produced in the effluent as a result of removing the surfactant Ultrawet K from the wastewater. After these solids are removed from the effluent via a clarifier or settling basin, they should be disposed of as solid waste. Compliance may be a function of the total amount generated, as the Resource Conservation and Recovery Act currently has a 1,000-kilograms-per-month exemption.

4.1.4 Noise. The 50-foot, A-weighted sound level of 87 dBA would cause significant communications problems to those individuals located outside the trainer. This may, in turn, interfere with the smooth conduct of any training scenarios. Although a more detailed noise analysis would be required to identify specific machine noise sources and determine the magnitude of each, it was possible through an aural evaluation and knowledge of machine operation to identify several contributors to the overall noise level. These contributors include the gasoline engine-driving unit, the air blower, the combustion chamber, the fogger nozzle, and panels of the machine enclosure. Of these, the most important are the gasoline engine, the fogger nozzle, and enclosure panels. (See Section 4.3.4 on speech interference.)

Tifa, Ltd., manufacturer of the smoke generator, has several options available that will reduce machine noise significantly. These options include the following:

- Replacing the gasoline engine with an electric motor and changing to a propane-fired burner

- Providing a complete machine enclosure

- Damping enclosure panels and lining enclosures with sound-absorbing materials.

Because the fogger nozzle is outside the machine enclosure and represents a significant source of noise in its own right, a separate partial enclosure for the nozzle may be required.

4.1.5 Meeting environmental standards. The 19F1 trainer is generally in compliance with applicable environmental standards; however, several areas could potentially result in noncompliance:

- The visible emission of triarylphosphate as a smoke from the facility may cause a violation of the opacity standard in several states. This should be verified with authorities in each state scheduled for a training facility to ascertain whether certain opacity exemptions might apply.

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- The BOD concentrations in both the LDQI and UDQII
  effluents exceed the acceptable standard for San Diego
  and thus may require some pretreatment. Due to the
  depressed BOD concentrations observed, some
  pretreatment may also be required at other sites.

- The pH values of both quadrants' effluents and the
  suspended solids concentrations of the LDQI effluent
  are just within the standards for certain states.
  This would indicate that slight variations in the
  wastewater content might bring it into noncompliance
  with one or more standards.

- The variability in flow rate to the POTW along with
  the organic surfactant wastewaters from the trainer
  may adversely affect the efficiency of the biological
  treatment portion of a treatment plant, depending on
  its size. If this arises, some form of flow control
  might be required for disposal to the smaller
  treatment plants.

- The presence of the surfactant Ultrawet K in the
  effluent presents the potential for foaming. This
  foaming could be excessive in a treatment plant that
  incorporates aeration as part of its treatment
  process. However, antifoaming agents could readily
  solve this problem if it arises.

- If the need arises for surfactant removal, any
  biological solids produced in the effluent as a result
  of surfactant removal must be removed from the
  effluent and disposed of as solid waste.

- The noise levels outside the 19F1 trainer due to the
  operation of the smoke generator are sufficient to
  cause significant communication problems. This might,
  in turn, detract from the efficiency and safety of the
  trainer operation.

Potential facility modifications or actions that may be taken
to correct or minimize these problems are discussed in
Chapter 5.

4.2 <u>Health effects</u>. Although the primary focus of this
phase of the assignment was to evaluate the major environmental
parameters of concern, we are able to use the data to make an
assessment of the health aspects of the 19F1 AFFT. An
assessment of the potential health effects to 19F1 AFFT
personnel involves consideration of the specific groups at risk
and the potential for acute and chronic exposures and effects.

Acute exposures are those situations where an individual is exposed to a contaminant for relatively short periods of time, perhaps at intermittent intervals. Chronic exposures refer to those situations where the individual is exposed to a contaminant for long periods of time (i.e., years). An acute effect is the short-term response from an acute exposure. A chronic effect is the long-term organism response from either a short-term or chronic exposure.

4.2.1 Acute exposure. This assessment of the health of personnel involved with training in the Advanced Firefighter Trainer assumes that each individual entering the training building will be supplied with a self-contained breathing apparatus. As outlined during the initial series of atmospheric tests (Phase I) and confirmed by the data collected during this phase of the assignment, the internal atmosphere of the 19F1 AFFT during operation contains sufficient levels of toxic materials that are "immediately dangerous to life or health" to require personnel entering the facility to use adequate respiratory protection. Specific characterizations of the health effects are further detailed in Sections 4.2.3 through 4.2.5.

The dermal absorption of toxic materials will be minimized with use of the currently available protective apparel. The use of protective apparel will also serve as protection from contact with the fire itself (i.e., burns). This protective apparel coupled with proper personal hygiene is expected to sufficiently protect the personnel involved with the fire-fighting exercises from exposure to toxic materials to the greatest extent possible while maintaining adequate mobility for training exercises.

Although the individual is well protected from exposure to potentially toxic chemical agents, he is exposed to an intense physical agent--heat. The heat generated by the fireplaces during the training exercise is necessary to simulate actual fire conditions for the trainees. However, heat stress represents a potentially acute response of unacclimatized personnel working in the intense heat environment of the fire fighter trainer. The evaluation of the potential for heat stress is further detailed in Section 4.2.4.

4.2.2 Chronic exposure. As outlined in the initial phase of the assignment, the instructors at the training facilities should be considered as a separate group of individuals because they are chronically exposed to the adverse conditions in the fire fighter trainer. The instructors are considered to be the largest group at risk for chronic effects.

In addition to being exposed to these adverse conditions on a daily basis, the work practices of the instructors were observed to be poor with regard to health protective measures. Improper or no respiratory protective equipment was used during operational fire-fighting training exercises observed during site visits. These poor practices will create both an increased risk of adverse chronic health effects from exposures to high levels of toxic materials repeatedly over long periods of time, as well as a great risk of acute effects from acute exposures to high concentrations of these toxic agents. These instructors will be entering areas that may be immediately dangerous to life and health.

Assuming the instructors' work practices as a group are improved, and appropriate respiratory protective equipment is used, the risk of a health hazard can be drastically reduced. However, as stressed in our Phase I report, it would be advantageous to maintain an active medical follow-up program for those individuals.

Heat stress should be less of a concern for the instructors because they will be acclimatized. However, the potential for heat stress remains an area for concern because the work conditions are adverse even for the acclimatized individual.

4.2.3 Internal atmospheres. The majority of the data collected, with the exception of temperature and simulated smoke concentrations, focused on environmental emissions. However, to the extent possible, the emissions data can be closely approximated to internal atmosphere, especially for gases. However, some of the backup monitoring data collected included internal quadrant conditions. In general, gas concentrations will not be drastically different between the room and a close-by actively ventilating stack. Variations in concentrations can and do occur very close to the points of generation.

4.2.3.1 Gases and vapors. As expected, a number of gases and vapors are present in the internal atmosphere of the operating fire fighter. In addition to propane, triaryl-phosphate and the surrogate extinguishment agents, the decomposition products of these materials are present (i.e., CO, CO_2, etc.).

Some of the potential decomposition products of each of these materials include the following:

- Propane: Carbon dioxide, carbon monoxide, oxides of nitrogen, and unburned hydrocarbons (mostly propane due to incomplete combustion)

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- Foam: Carbon dioxide, carbon monoxide, water, and possibly oxides of sulfur (although not detectable at all with diluted material, only with the use of pure concentrate)

- Smoke: Carbon dioxide, carbon monoxide, oxides of nitrogen, and unburned hydrocarbons.

The concentrations of each of these materials will vary with a number of parameters including the following:

- Flame temperatures

- Activity scenario including generation and application times

- Ratio of flame to room volume

- Ventilation.

As outlined in Section 3.5, the onsite sampling revealed concentrations of several contaminants that require consideration be given to their potential exposure hazard.

As cited previously, the concentrations observed further justify the need for respiratory protection. Specifically, the following assessments can be made based on the sampling results:

- Carbon monoxide levels (maximums of 10,000 ppm for the UDQII and 5,000 ppm for the LDQI) are significantly higher than the permissible ACGIH Short-Term Exposure Level (STEL) of 400 ppm. STEL, as defined by ACGIH, should be considered the Maximum Acceptable Concentration (or ceiling) and not to be exceeded at any time during the 15-minute excursion period.

- Carbon dioxide levels (maximums of 57,000 ppm for the UDQII and 25,000 ppm for the LDQI) exceed the current acceptable STEL of 15,000 ppm.

- Nitric oxide concentrations (maximums of 10 ppm for the UDQII and 16 ppm for the LDQI) do not exceed the current acceptable STEL of 35 ppm or the time-weighted average concentration of 25 ppm.

- Oxygen levels (observed minimums as low as 15.5 percent for periods of several seconds) in the trainer during specific periods of the test scenarios may be considered inadequate for human entry as determined by NAVSEA, which considers anything less than outdoor

conditions as unsafe for entry. This also would not
be acceptable by ACGIH, which identifies 18 percent as
an adequate minimum concentration without requiring
appropriate respiratory protection.

The backup monitoring equipment used to supplement the ATS
installed equipment permitted evaluation of the concentration
excursions that had been observed during the initial assignment
as well as during this phase. The concentrations' maximum
values summarized in Section 3.5 will permit appropriate
recalibration of the installed monitoring equipment to detect
contaminants over a broader scale. This was especially
important for carbon monoxide, carbon dioxide, and hydrocarbons.

4.2.3.2 Aerosols (dusts, smokes, and fogs). The aerosols
present in the internal atmosphere of the 19F1 AFFT during
operation consist primarily of sodium bicarbonate and
silicates, triarylphosphate, and some organic particulates. In
addition, an intense water fog was present during the majority
of the fire-fighting scenarios. Only the particulate
concentration of the triarylphosphate was determined in this
assignment.

The sodium bicarbonate (Grade No. 2) is a relatively coarse
material. It settles significantly faster than the original
PKP powder proposed for use. Therefore, dust exposure is
intuitively and visually reduced. This is further supported by
the dramatically reduced particulate emissions observed as
outlined in Section 3.5.

Some small quantities of smoke were also observed from the
propane combustion in the fireplace under normal fire
conditions.

The triarylphosphate concentrations were estimated to be
about 1,020 mg/m^3 for about 1 minute during the smoke
sequence in the scenarios. This material does not have a
health standard set for it. However, this material can be
considered a nuisance particulate having a threshold limit
value (8 hour time-weighted average) of 10 mg/m^3. The
concentrations observed may not exceed this value on a
time-weighted average basis, although it acts as an additional
loading factor to the total dust burden from the powder
extinguishing agent.

The use of self-contained respirators as previously
recommended would alleviate concern for these potential
nuisance particulate exposures. Based on the currently
available information, the triarylphosphate does not appear to
present a health hazard due to inhalation or skin absorption

under the recommended conditions for use in this report (see Section 5.2). The respirator further eliminates the inhalation factor as a problem for any concern at any concentration.

4.2.3.3 AFFT as a confined workplace environment. The 19F1 AFFT operates as a confined space. Therefore, it should be assessed for its safety compliance based on criteria for confined workplace environments (NAVSEA gas-free engineering and NIOSH criteria). Some concerns relate to potential health hazards as outlined in this chapter; however, as a confined workplace environment, attention needs to be directed to imminent safety hazards involved with a hot open flame in a confined space, such as oxygen deficiencies, uncontrolled fires, and explosions as outlined in Section 4.3.

4.2.4 Heat stress. A primary objective in the development of a training program of this type is for effective training without duly injuring the trainees. The potential exists for unacclimatized individuals to suffer from heat stress during the prescribed advanced fire-fighting training program as outlined in the Phase I report.

A detailed evaluation of heat stress involves intensive monitoring of physical conditions (i.e., temperature, air velocity, humidity, and apparel), physiological parameters (i.e., metabolic work load, pulse rate, respiration rate, and sweat rates), and administrative parameters (i.e., work-rest regime). In order to rapidly evaluate the possible existence of a heat stress situation, the Wet Bulb-Globe Thermometer Index (WBGT) was employed as recommended by the American Conference of Governmental Industrial Hygienists.

Using the temperature data collected during the onsite sampling program, estimates could be made of the potential for heat stress situations. The calculation made for the WBGT is based on the values being taken indoors, an estimated heavy work load, and a work-rest regime of about 50 percent each per hour. The permissible heat-exposure threshold limit value for these conditions would be approximately 30°C (86°F) WBGT. This value assumes the following:

- Individuals are acclimatized and fully clothed (but not in fire-fighting apparel).

- Adequate water and salt intake are practiced by the individuals.

- Work-rest places are in the same WBGT.

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This value refers to heat stress conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects. Higher heat-exposure limits are permitted if additional resting time is allowed. Extra caution must be used when unacclimatized workers must be exposed to heat stress conditions.

Based on the data collected onsite as illustrated in Table 22 (Section 3.5.4), a typical WBGT index for the LDQI was determined to be approximtely 50°C (122°F) WBGT. The application of the low velocity fogs throughout the training scenario was observed to reduce temperatures. Temperatures were observed to be 70° hotter during a run where the fog had not been applied. This cooling effect is clearly an effective means of reducing the operating temperatures. However, the fog had a cooling effect on the globe temperature measurements, which would generally be expected to exceed both wet and dry bulb readings. The shortness of the temperature rise cycle further prevents adequate equilibration; therefore, the globe temperatures observed are probably lower than the values expected under a steady state condition. This phenomenon also excludes the use of the theoretical determination of Heat Stress Indices as developed by Belding & Hatch.

The potential exists for a heat stress situation to occur especially in the repeated use of the bilge fire training scenario with the same trainees. The work-rest regime would certainly influence the probability for heat stress to occur. Several industry studies have demonstrated that thermal stress is an important factor where the worker has to make critical decisions, or to perform fast and skillful actions because safety will depend on constant alertness. The number of errors will increase if the worker is exposed to heat even before the body temperature or pulse rate reaches critical levels. The intense heat of fire-fighting conditions establishes a situation where impaired mental performance can be expected, certainly as it would be expected in an actual fire situation.

The primary emphasis is on reducing the number of heat casualties rather than the direct application to an industrial work situation. The classical symptoms of heat stress and heat disorders are illustrated in Figure 36.

The optimum approach for assessing the extent of heat stress in the fire fighter trainer will require biological monitoring of a select group of trainees. This type of program could be performed both at the 19Fl AFFT and as a traditional fire-fighting training exercise for a comparison to the stress trainees are currently under. This type of monitoring has been successfully done in a number of industrial and military
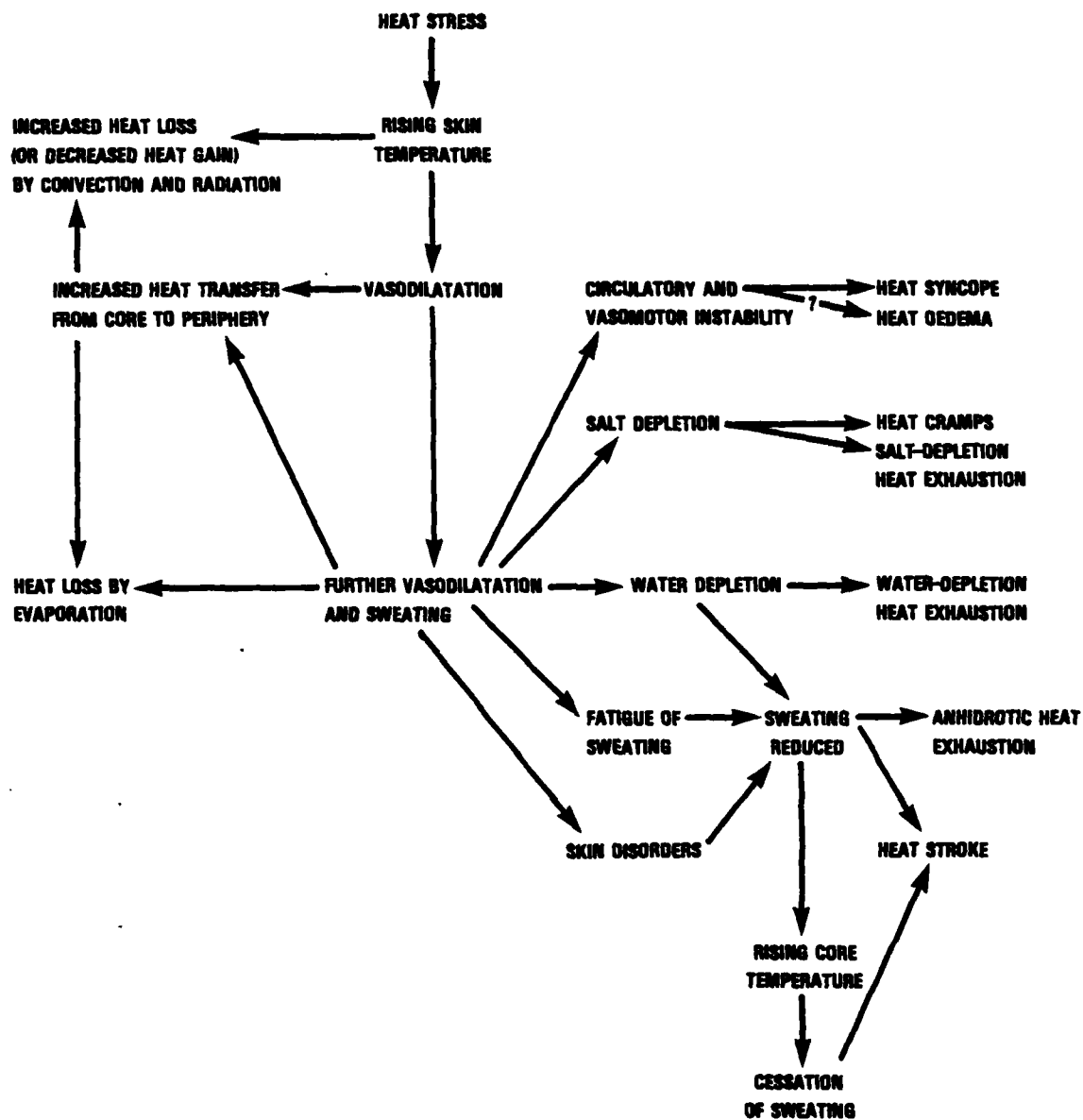
Figure 36.   Heat Stress and Disorder

situations. The Naval Medical Research Institute in Bethesda, Maryland, has had extensive experience in this area and should be considered for assisting NTEC in actual field test medical evaluations.

4.2.5 Noise. The potential for adverse health effects from noise exists regarding the use of the triarylphosphate smoke generator. In addition to the verbal communications problem experienced by individuals located within 50 feet of the trainer, the noise levels as measured during onsite testing can present a potentially serious hazard to hearing. At a distance of 10 feet from the smoke generator, the A-weighted sound level was determined to be 96 dBA. If personnel are stationed within a 10-foot radius of the machine for periods of 3.5 hours during continuous operation, there will be a potential for hearing loss unless hearing protection is worn.

Before installing a Tifa Fogging Machine, the facility operator should consider available manufacturer's options for quieting the unit, as discussed in Section 4.1.4. In addition, suitable hearing protection should be used for personnel stationed within 10 feet of the fogger for extended periods of time. After equipment installation, sound measurements should be made to ensure that the level of noise is below that which will cause significant communication or hearing problems.

4.3 Safety factors. The ultimate safety of the 19F1 AFFT will be a major factor in its overall success as a training tool. As outlined in our Phase I report, several key issues have been raised concerning the safety of the trainer. These issues include the following:

- Does the 19F1 AFFT comply with current OSHA safety standards regarding:

  - Walking/working surfaces?
  - Means of egress?
  - Approved NEC equipment?
  - NFPA guidelines?

- Does the 19F1 AFFT require consideration as a confined work space, and does it conform to National Institute of Occupational Safety and Health (NIOSH) criteria?

- Is there a real potential for an uncontrolled fire and/or explosion within the fire fighter trainer during operation?

The issues concerning the initial point on general OSHA safety standards were addressed in our Phase I report. The problems identified were corrected prior to this phase of the assignment.

As previously outlined in our Phase I report, the fire fighter trainer should be considered a confined work space environment, and appropriate general work practices should be employed as recommended by NIOSH and NAVSEA. Based on the data collected during this assignment, the stack exhaust stream concentrations for hydrocarbons (primarily propane) exceeded the acceptable standards set by NIOSH. NIOSH recommends that the maximum exhaust concentration be no more than 10 percent of the lower flammable limit (LFL) or the permissible exposure limit (PEL). This would be equivalent to a maximum stack stream concentration of no more than 1,000 ppm (OSHA-PEL) rather than 2,200 ppm (10 percent LFL). These concentrations were consistently exceeded during parts of all three training scenarios.

The overall potential for an uncontrolled fire and/or explosion within the trainer during operation was addressed in the Phase I report. Three major concerns were identified as presenting a significant potential hazard for uncontrolled fires and or explosions. The materials of concern included propane, propylene glycol fog, and propane and propylene glycol mixture.

The decision was made by NTEC, based on our recommendations, that propylene glycol be substituted with triaryl-phosphate (TAP) as a simulated smoke for the onsite sampling program. The favorable characteristics of TAP eliminated the concerns identified with the use of propylene glycol.

The use of propane to operate the trainer fireplaces still presents a concern. Propane and TAP are discussed in the following sections as to their inherent flammability properties and their specific hazard potentials during trainer operation.

4.3.1 Simulated smoke. As discussed in detail in Sections 2.2.3 and 3.5.3, Chem Chex 220, triarylphosphate, was chosen as the optimal candidate for use as a smoke simulant during the onsite sampling program. An extremely dense smoke (less than 6-foot visibility approximately 20 seconds after initiation) was generated in a minimal amount of time (less than 10 seconds). The actual visibility at particular times during the beginning scenario was less than 1 foot. This dense smoke was generated from a minimal amount of material (approximately 0.17 liter).

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As expected, there were no problems concerning flammability with the use of this smoke in an open flame environment. The small quantities of material used precluded any concerns regarding potential explosions as might occur with other smokes requiring greater quantities of material for comparable effect.

The smoke seems to be ideal for obscuration and safety. These intense smoke levels generated could be considered the outer limits of utility, and the necessity for generation of additional quantities (for greater obscurity) of smoke is not justified.

4.3.2 Propane. Due to the inherent characteristics of the material, propane is readily usable as a fuel source for the fire fighter fireplaces. Under normal operating conditions, the propane is expected to be used in the fire with minimal release of unburned products to the surrounding environment.

Analysis of the hydrocarbon emissions in comparison to the scenario activities (Appendix F) and the composite figures in Section 4.5 revealed that significant amounts of propane are released into the training compartments during various scenario activities. This occurs primarily during periods of increased gas flow and flame suppression. There appears to be a time delay due to an increase in gas flow being translated into higher hydrocarbon emissions; thus, one observes a shift to the right when comparing the profiles. The cause of the heightened hydrocarbon levels is a function of both activities.

Maximum propane releases were primarily observed during the following activities:

- LDQI (oil bilge fire)

    - After cessation of surrogate PKP application (reflash period)

    - At the application of the high-velocity fog and the dwell

- UDQII (deep fat fryer)

    - Upon application of powder extinguishment

    - Continuing after scenario shutdown (gas flow shows this also)

- UDQII (rag bale)

    - Upon application of the high-velocity spray
    - Upon application of foam extinguishment.

At these points, a potentially explosive situation may exist in the scenario. The maximum ranges of hydrocarbon concentrations observed for the various fire scenarios had the following equivalent explosion potentials:

- Oil bilge 13.5 to 36 percent of the lower explosive limit (LEL)

- Deep fat fryer 4.5 to 22.7 percent of the LEL

- Rag bale 4.5 to 27.3 percent of the LEL

Although these values are well below the LELs, they do exceed acceptable values for safe work practices. NIOSH prohibits entry to a confined space for hot work if 10 percent of the lower flammable limit is exceeded. NAVSEA (gas-free engineering) recommends entrance only at near atmospheric conditions. Critical attention must be given to assure that the LEL (2.2 percent) of propane is not exceeded, even in small pockets within the trainer.

Specific engineering controls, primarily ventilation, will be required to lower the risk of explosion from excess propane during the training scenarios and to come into compliance with currently accepted practices.

4.3.3 Combustible gas indicators. The internal atmospheric conditions in the fire fighter trainer can have a considerable effect on the accurate response of the combustible gas indicators. Varying gas and vapor mixtures in the atmosphere can dramatically affect the indicator's response.

The sensitivity and accuracy of combustible gas indicators are affected by a wide range of conditions. These conditions include the presence of dust, high humidity, and temperature extremes. Recalibration of the detection equipment should be performed on a regular basis.

The data obtained from the ATS sensing equipment on the percent of the LELs appeared to be extremely low compared with the values determined for the hydrocarbon concentrations. It has since been determined that the sensor was not functioning correctly. The air intake was apparently being inhibited, resulting in dramatically lower readings than expected; yet, when calibrated, read accurately for standard concentrations. ATS has advised us that this problem is being reviewed with the equipment manufacturer, and appropriate modifications will be forthcoming.

4.3.4 Speech interference. The noise produced during the operation of the smoke generator as described in Sections 3.5 and 4.1 also represents a potential safety problem during training. The interference with speech (Table 27) can inhibit effective training as well as verbal directions in emergency situations.

Noise can mask or "blot out" speech sounds reducing the intelligibility of messages. Laboratory studies of these effects have appraised the disruptive potential of the noise by its "speech interference level," which is the average sound pressure level in the 500-, 1,000-, 2,000- and 4,000-Hz octave bands. The distances at which difficult messages can be conveyed reliably are shown in Table 27 as a function of the speech interference level. Simple, redundant messages normally used at work can be understood at greater distances.

The speech interference level for the smoke generator was determined to be 92 dB with the burner on and 94 dB with the burner off. Appropriate noise-level suppression will alleviate this problem, or noise-cancelling communications equipment may be used.

4.4 Heat/operating temperatures. Some concerns have been raised addressing the functional operation of the trainer under internal environmental temperatures. These concerns deal with both the proper operation of the devices as well as the structural integrity of the facility itself.

A criterion had been set for material tolerances to intense heat. This criterion, as defined by ATS, was equivalent to a maximum average ambient air temperature of 125°F for up to 15 minutes with a ceiling of 150°F for no more than 1 minute during the operating period. This criterion was consistently exceeded during the scenarios in both the lower and upper deck quadrants (Tables 19 and 20).

4.4.1 Device operation. The operating temperatures observed during the onsite sampling program have consistently exceeded the criteria set for safe and proper operation of the devices. This excessive heat could result in malfunctions of the devices. The specific issues for concern with the equipment are left for the manufacturer to detail.

4.4.2 Structural concerns. Specific structural concerns have been raised about the structural integrity of the facility as a function of the intense heat cycles of the proposed training exercises. There is a question as to the ability of the facility's concrete and steel construction to withstand the constant cyclic expansion and contraction during operation.

TABLE 27. MAXIMUM SPEECH INTERFERENCE LEVELS
FOR RELIABLE COMMUNICATION
AT VARIOUS DISTANCES AND VOCAL EFFORTS

Distance (feet)	Vocal Effort			
	Normal	Raised	Loud	Shout
0.5	76	82	88	94
1	70	76	82	88
2	64	70	76	82
4	58	64	70	76
8	52	58	64	70
16	46	52	58	64
32	40	46	52	68

An evaluation of this potential problem is beyond the scope of this study on environmental concerns. The matter should be addressed by structural engineering consultants in the interests of long-term safe operation of the facility.

4.5 <u>Relation of operating parameters to scenario activities</u>. In order to better define the actual emission concentrations as they relate to specific scenario activities, Booz, Allen composed a series of typical profiles based upon the new data collected for each operating parameter versus the scenario activity occurring. These parameters included:

- Gaseous emissions
- Gas flow/consumption
- Temperatures.

Figures 37 through 52 present these typical profiles, with estimates of the concentrations occurring at specific scenario events. These estimates, however, reflect considerable variability (ranging from 20 to 80 percent; typically, a 95 percent confidence band would show about a 40 to 50 percent variability) of the small data base used for the profiles. However, the basic profiles were consistent for the majority of the scenario runs observed. These profiles are primarily informative from an operational standpoint rather than focusing on their health hazard significance. The critical health concerns are essentially the maximum concentrations and their time durations.

4.5.1 Profile summary: gaseous emissions/activities. The profiles of typical gaseous emissions (Figures 37 to 46) are summarized by relating concentration levels to activities occurring in the individual fireplace scenario.

4.5.1.1 Oil bilge fire (LDQI). The profile characteristics are as follows:

- CO--Concentrations follow a bimodal pattern with an increase after powder application and a greater increase during application of the high-velocity spray.

- CO_2--Concentrations follow a bimodal pattern with a constant increase until the initiation of the high-velocity spray. A second increase occurs during the reflash period with a gradual decrease after application of foam.

- O_2--Concentrations show two minor decreases: an initial one at initiation of the pilot, and a second decrease on application of the powder, which continues throughout the remaining scenario.
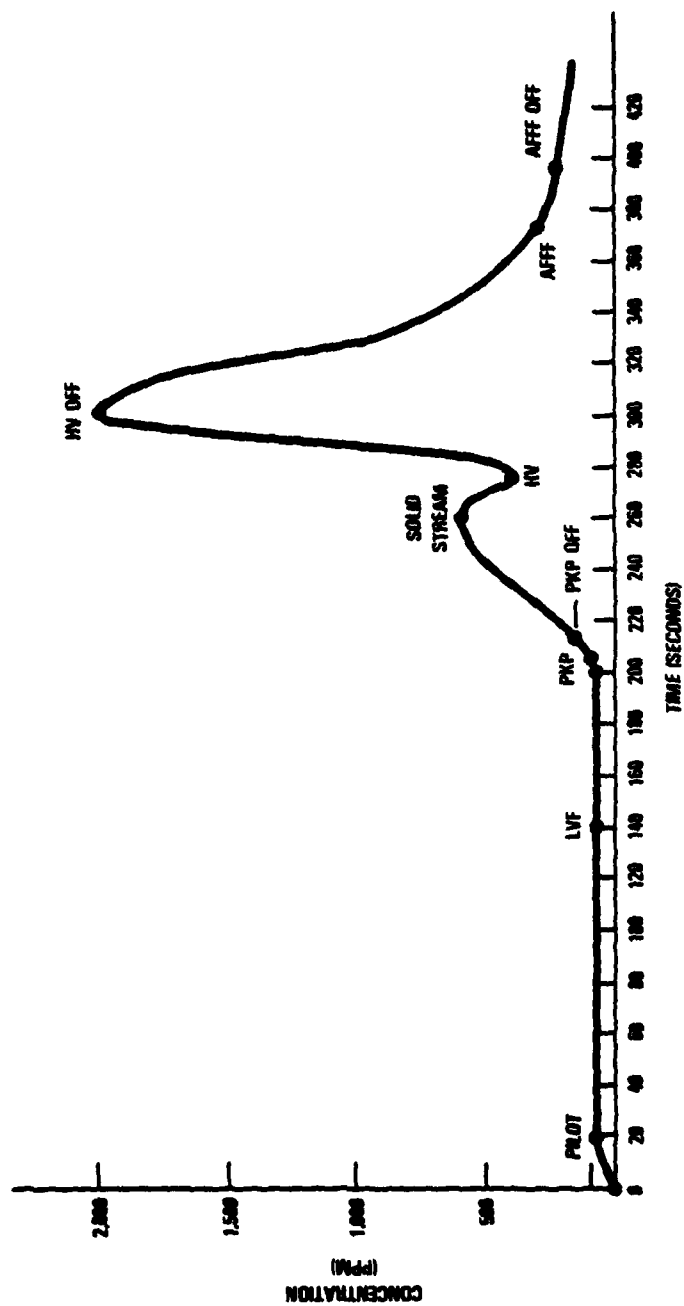
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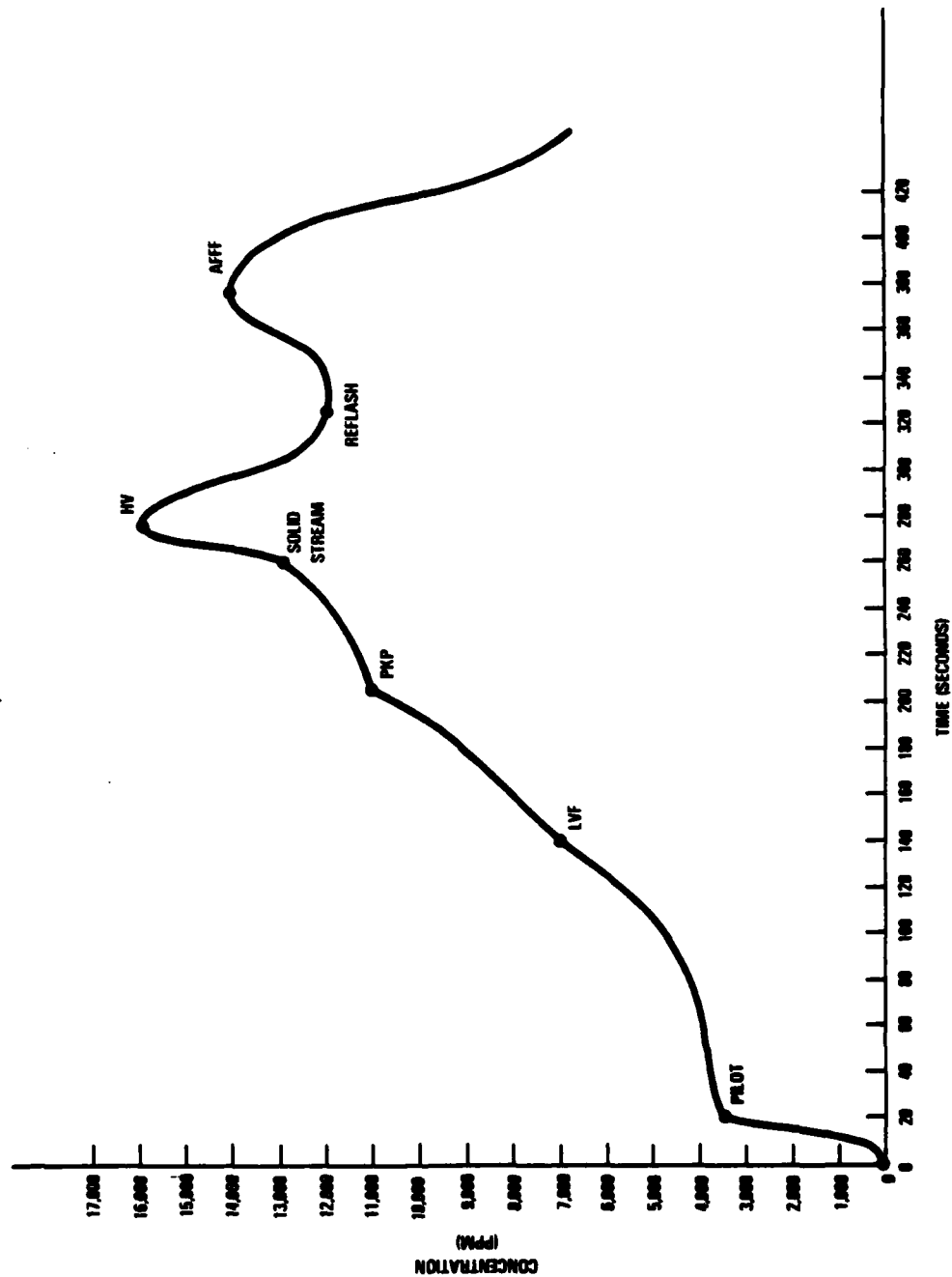Figure 37. LDOI Scenario - Typical Emissions Profile
for CO

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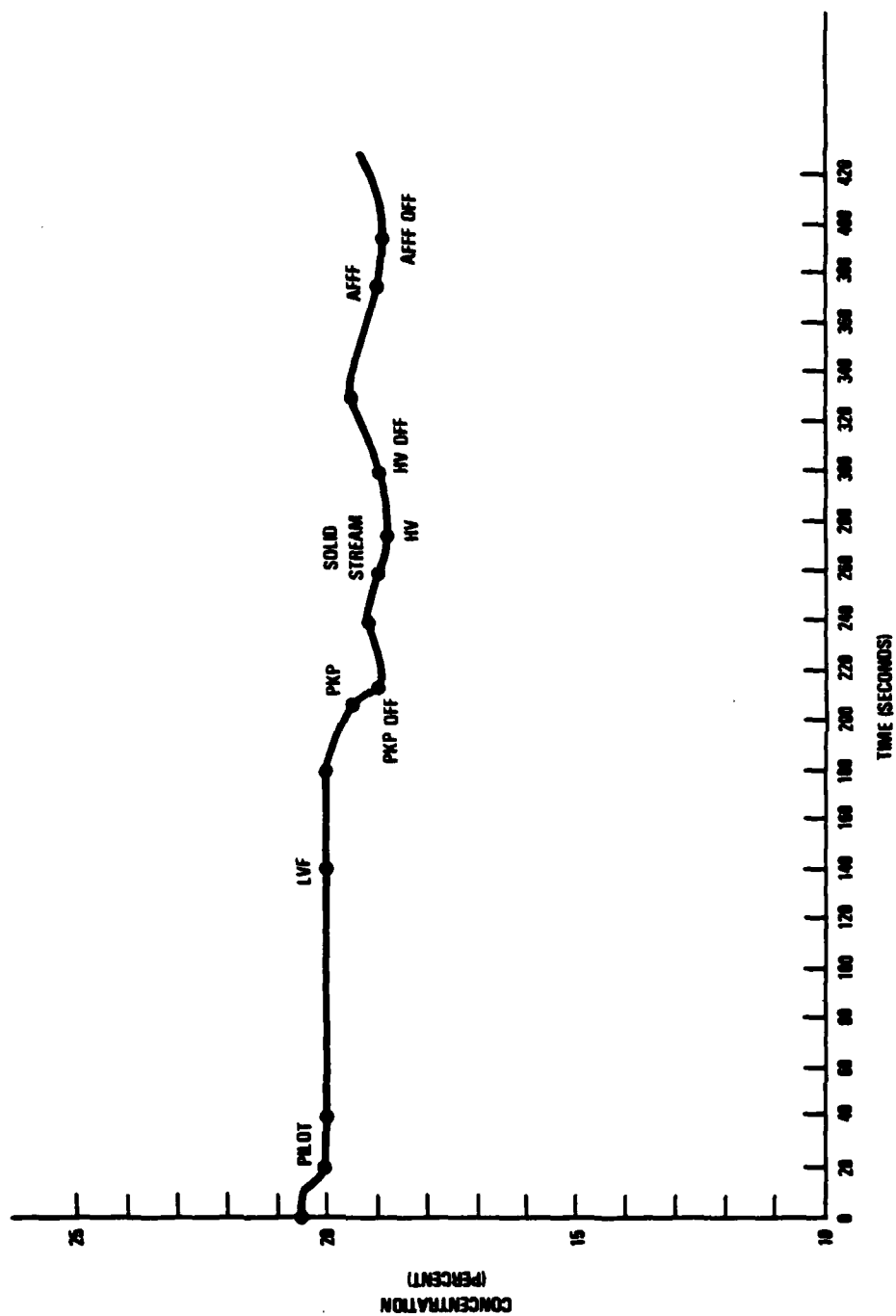Figure 38. LDQI Scenario - Typical Emissions Profile for CO_2

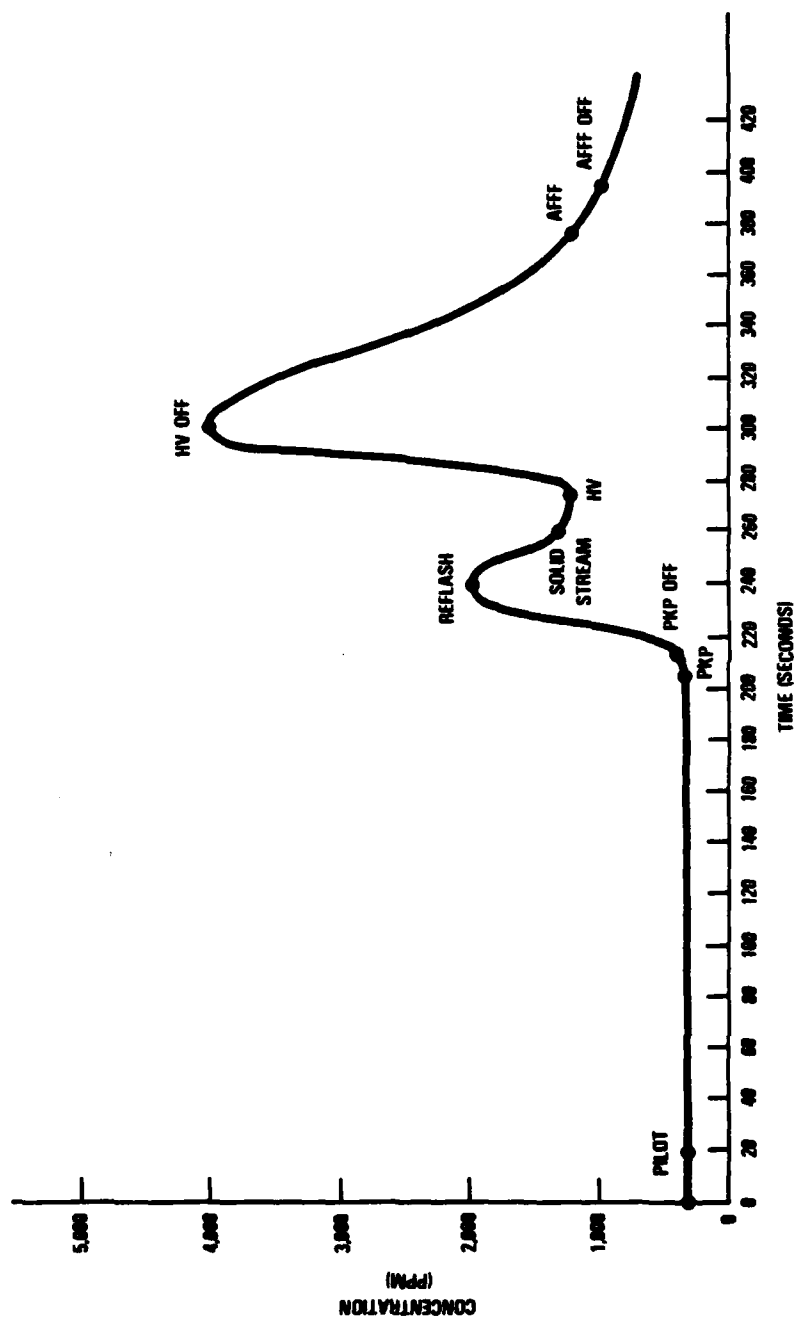Figure 39. LDOI Scenario - Typical Emissions Profile
for O_2

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Figure 40. LDQI Scenario - Typical Emissions Profile
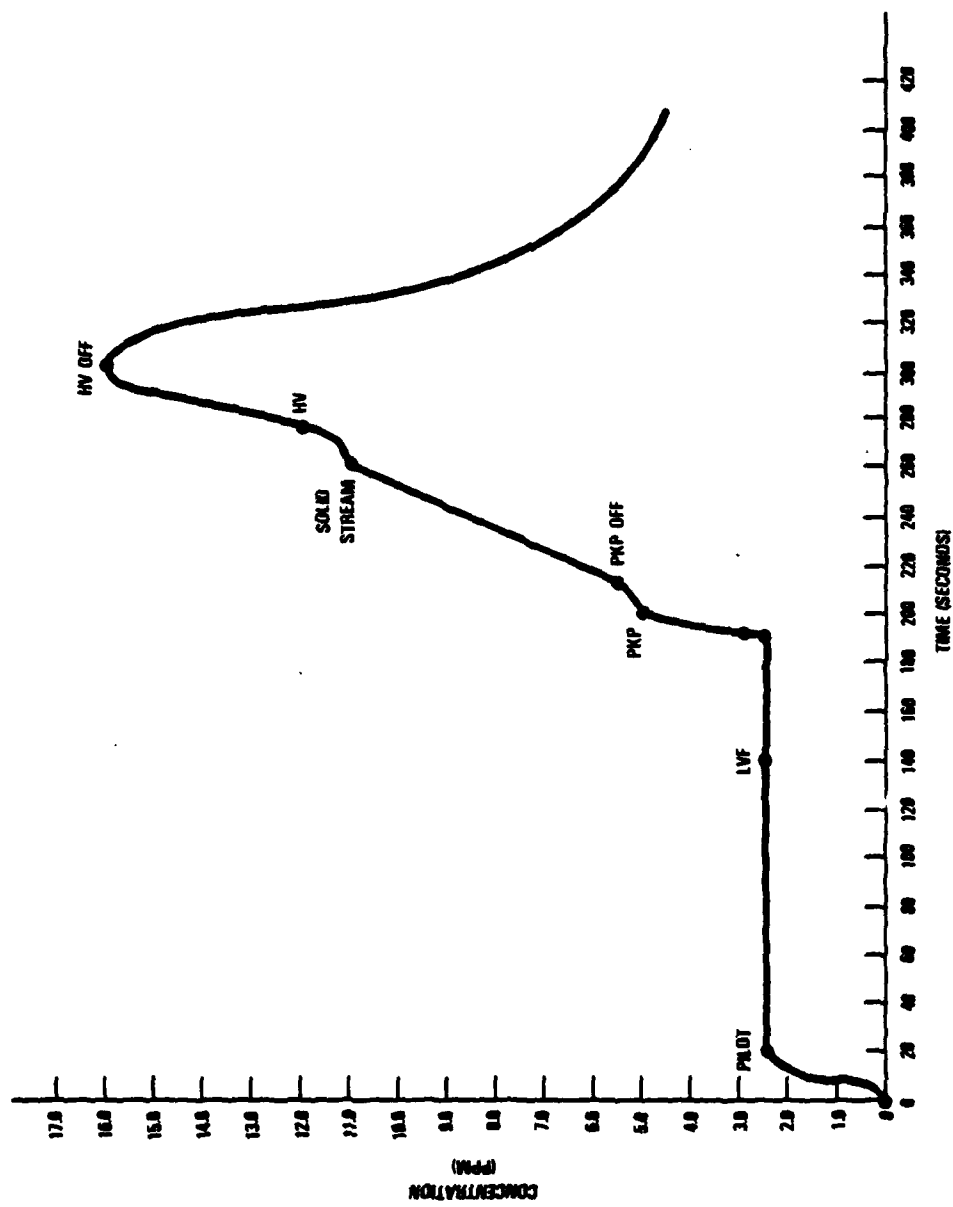for HC

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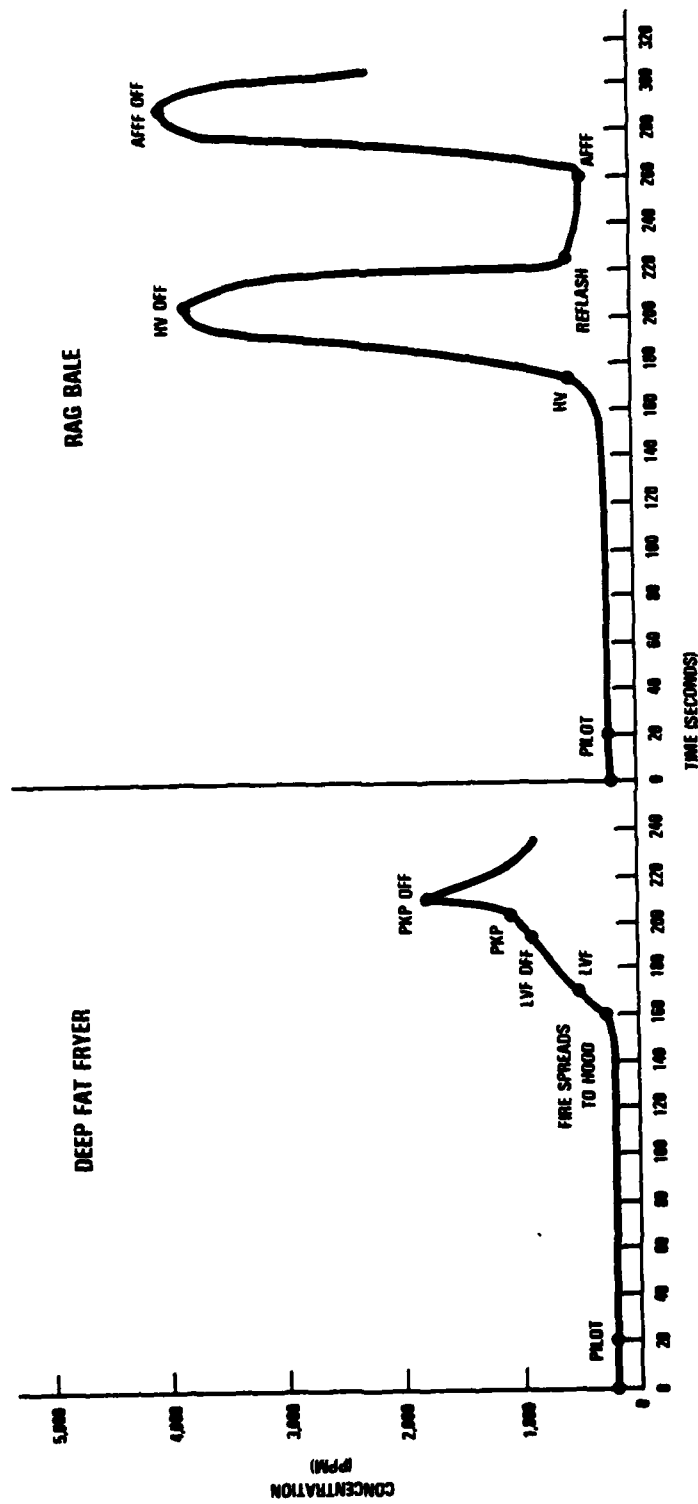
Figure A1. LDOI Scenario - Typical Emissions Profile for NOx

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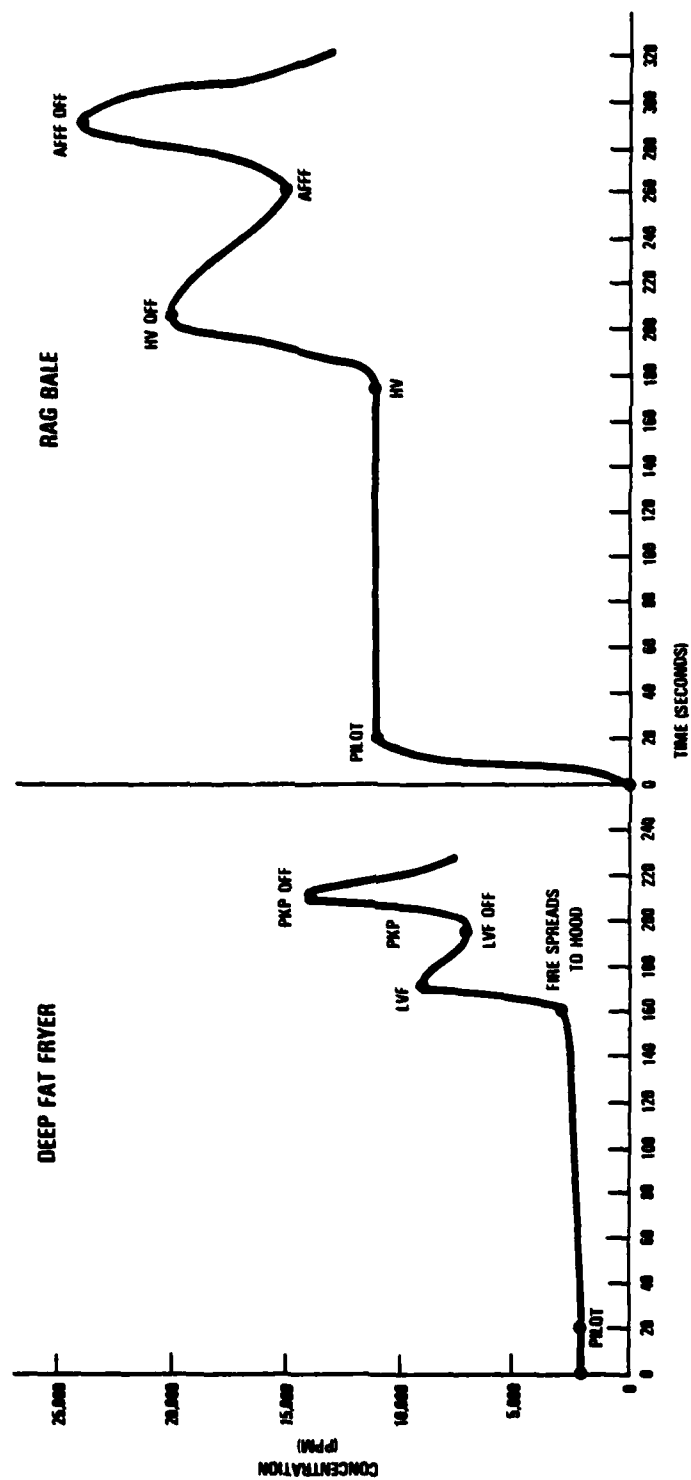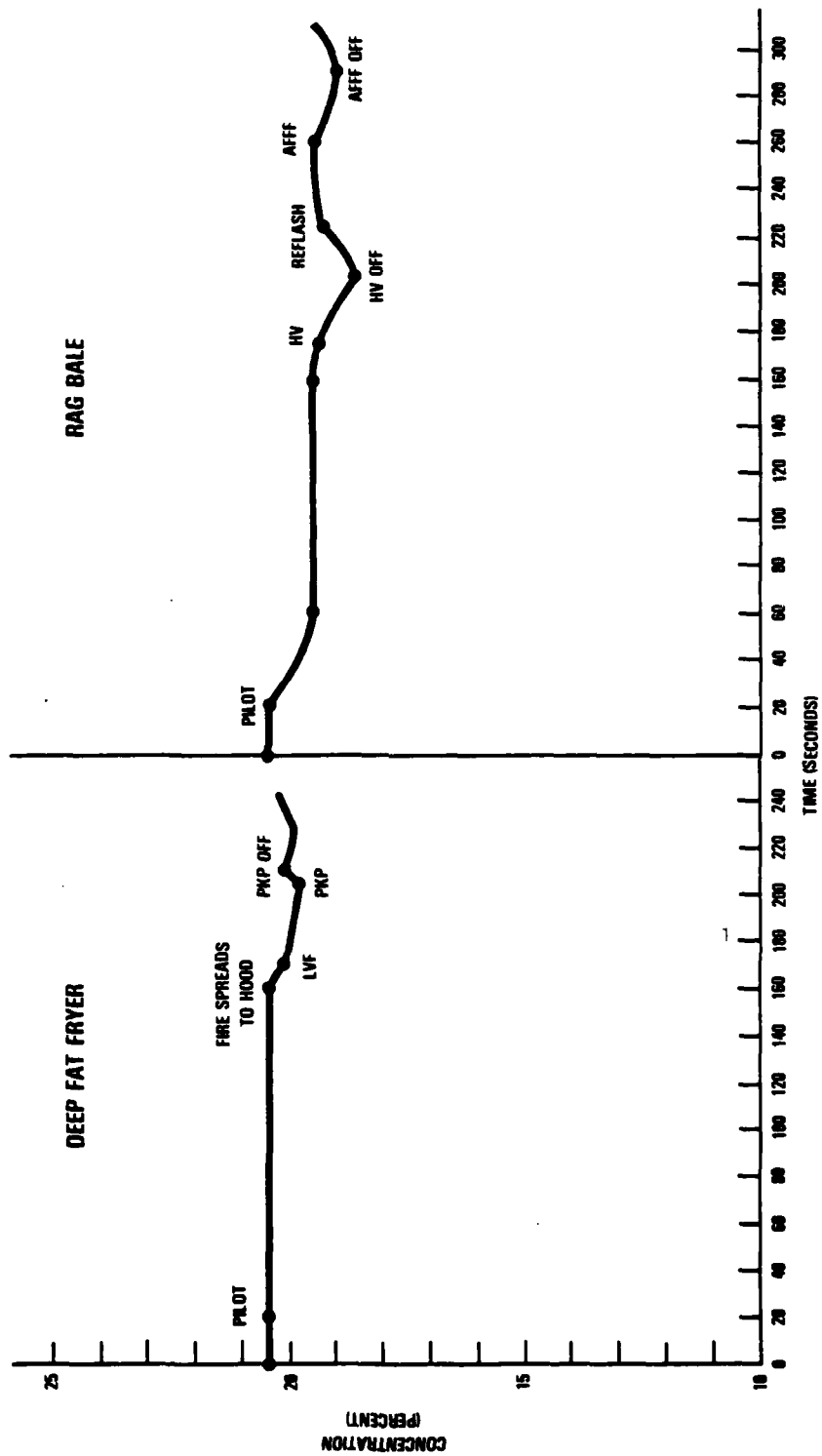Figure 42. UDQII Scenario - Typical Emissions Profile
for CO

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Figure 43. UDQII Scenario – Typical Emissions Profile
for CO2

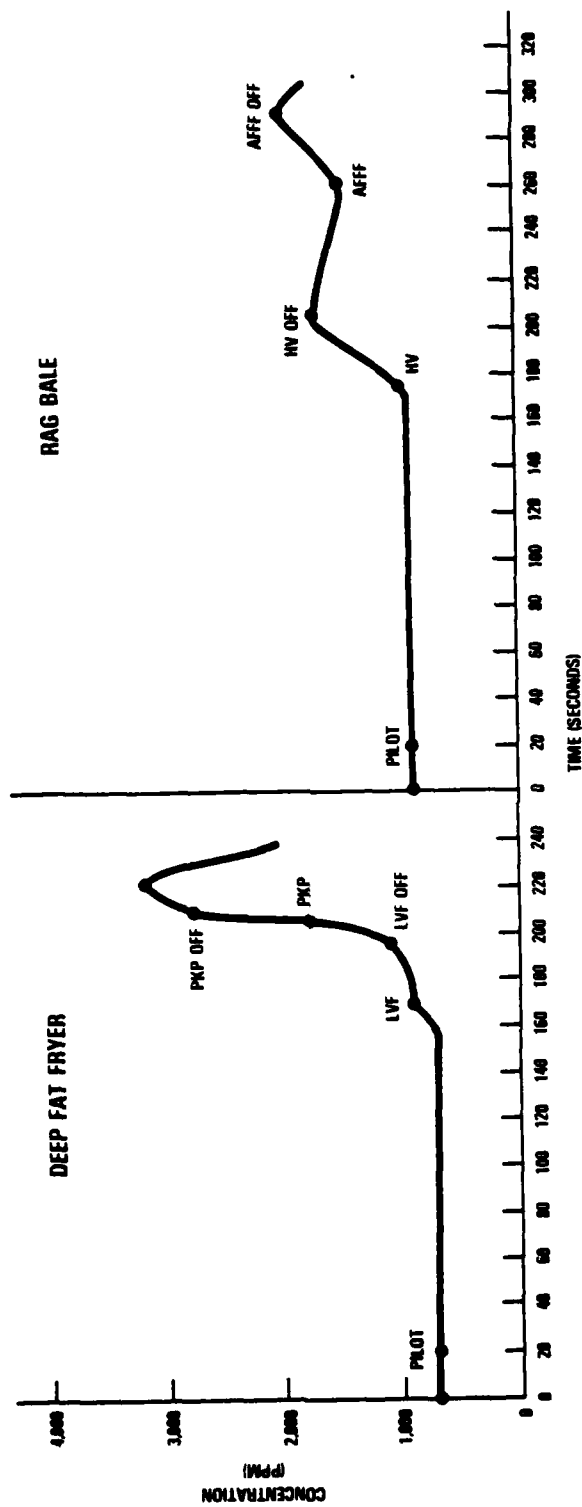Figure 44. UDQII Scenario - Typical Emissions Profile
for O2

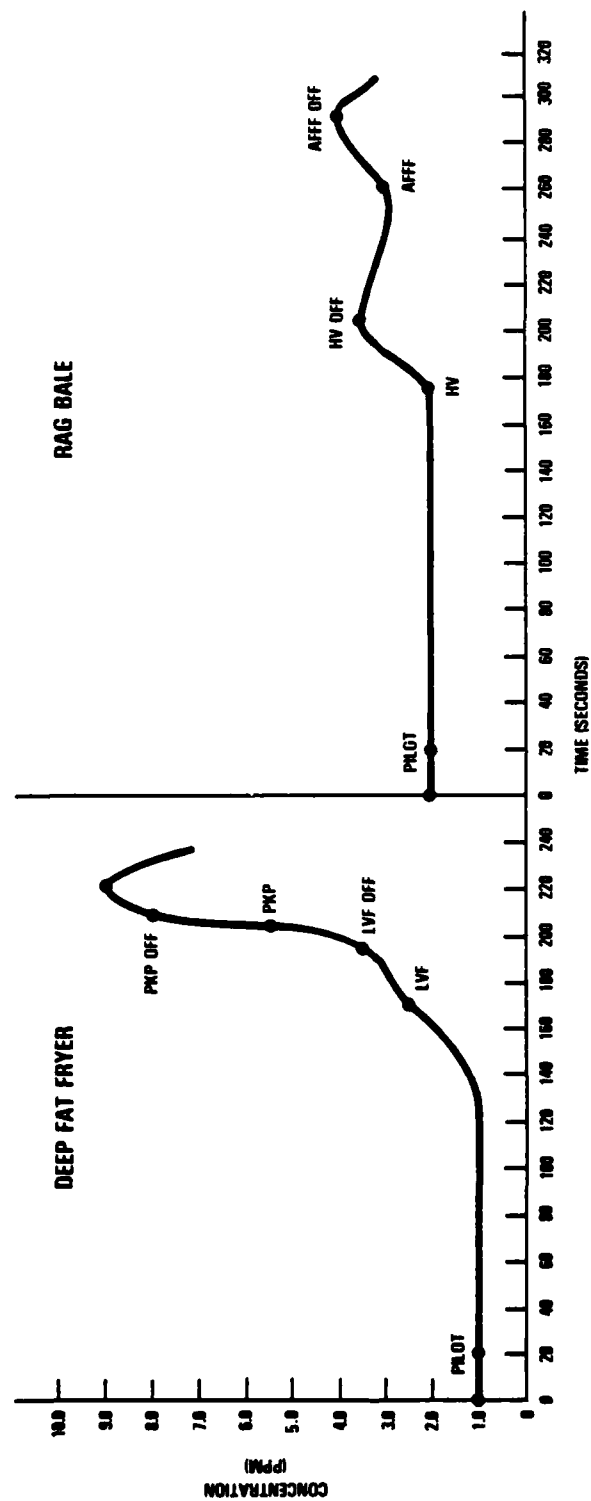Figure 45. UDQII Scenario – Typical Emissions Profile for HC

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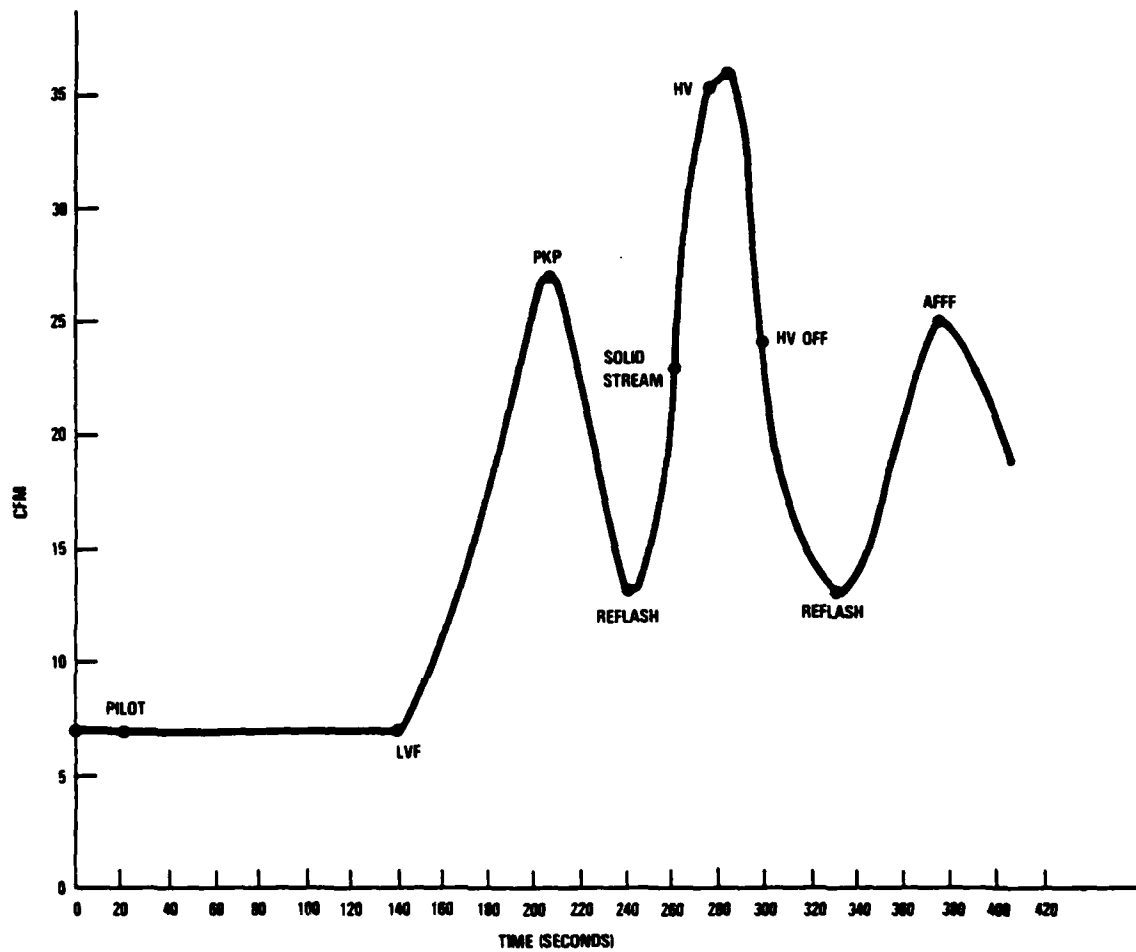Figure 46. UDQII Scenario - Typical Emissions Profile for NO$_x$

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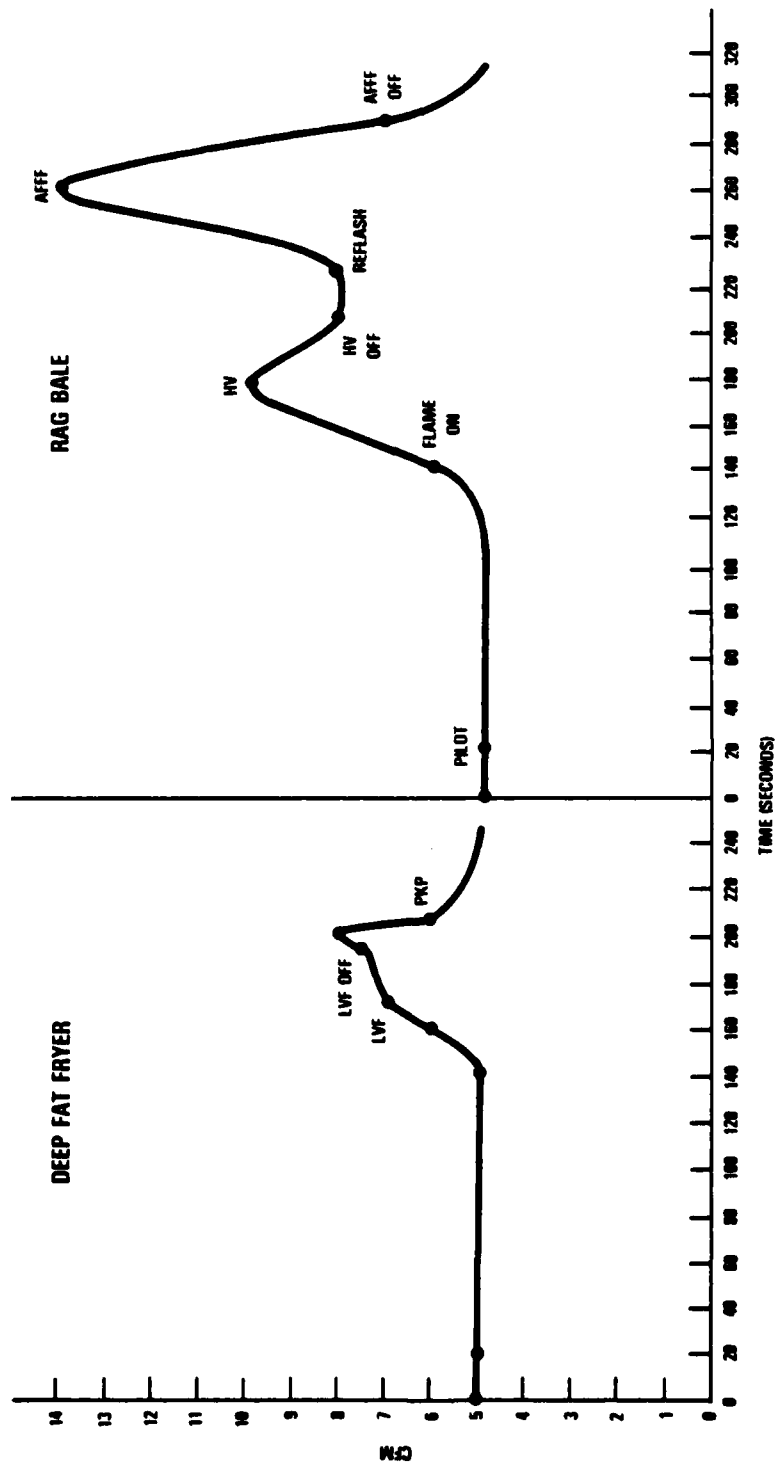Figure 47. LDQI Scenario - Typical Gas Flow Profile

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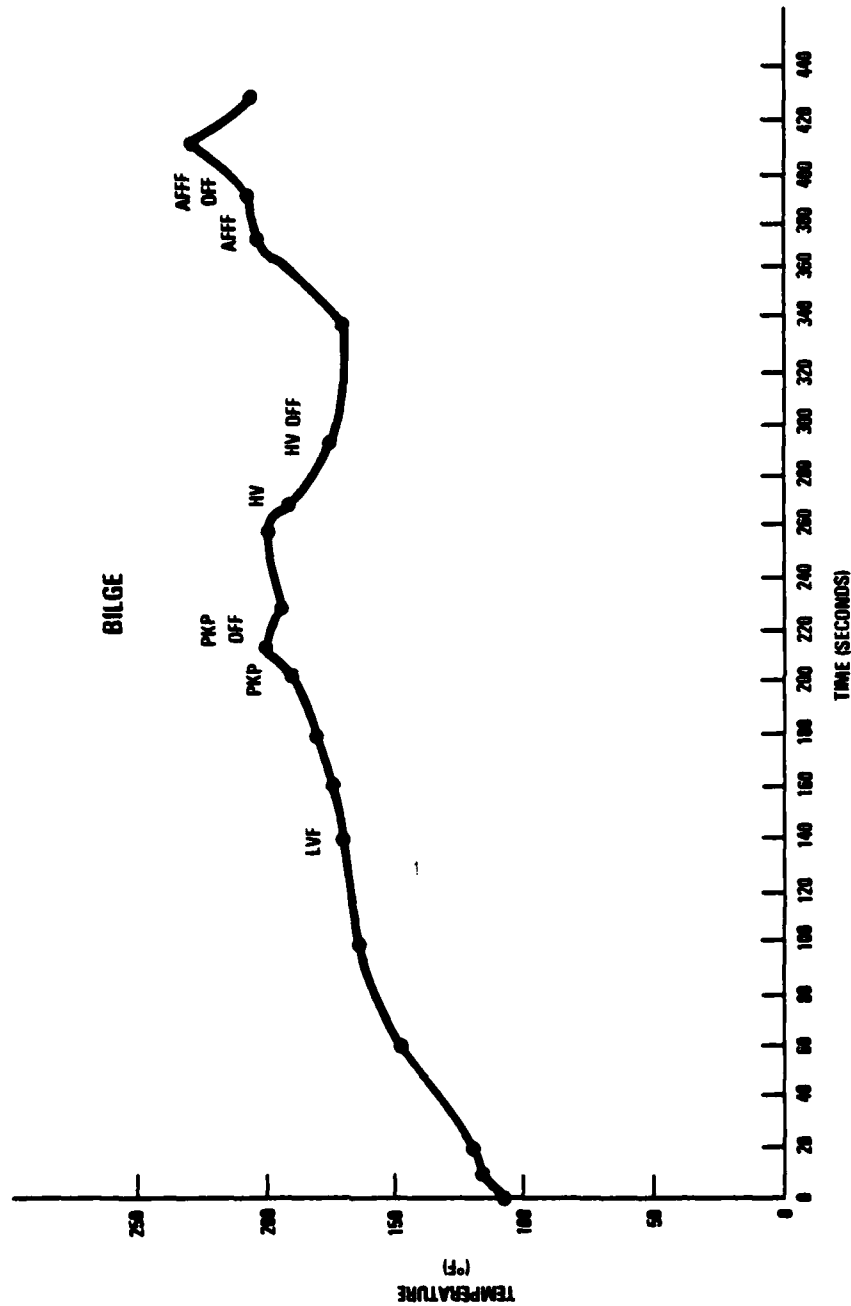Figure 48. UDQII Scenario – Typical Gas Flow Profile

Figure 49. LDOI Scenario - Typical Temperature Profile
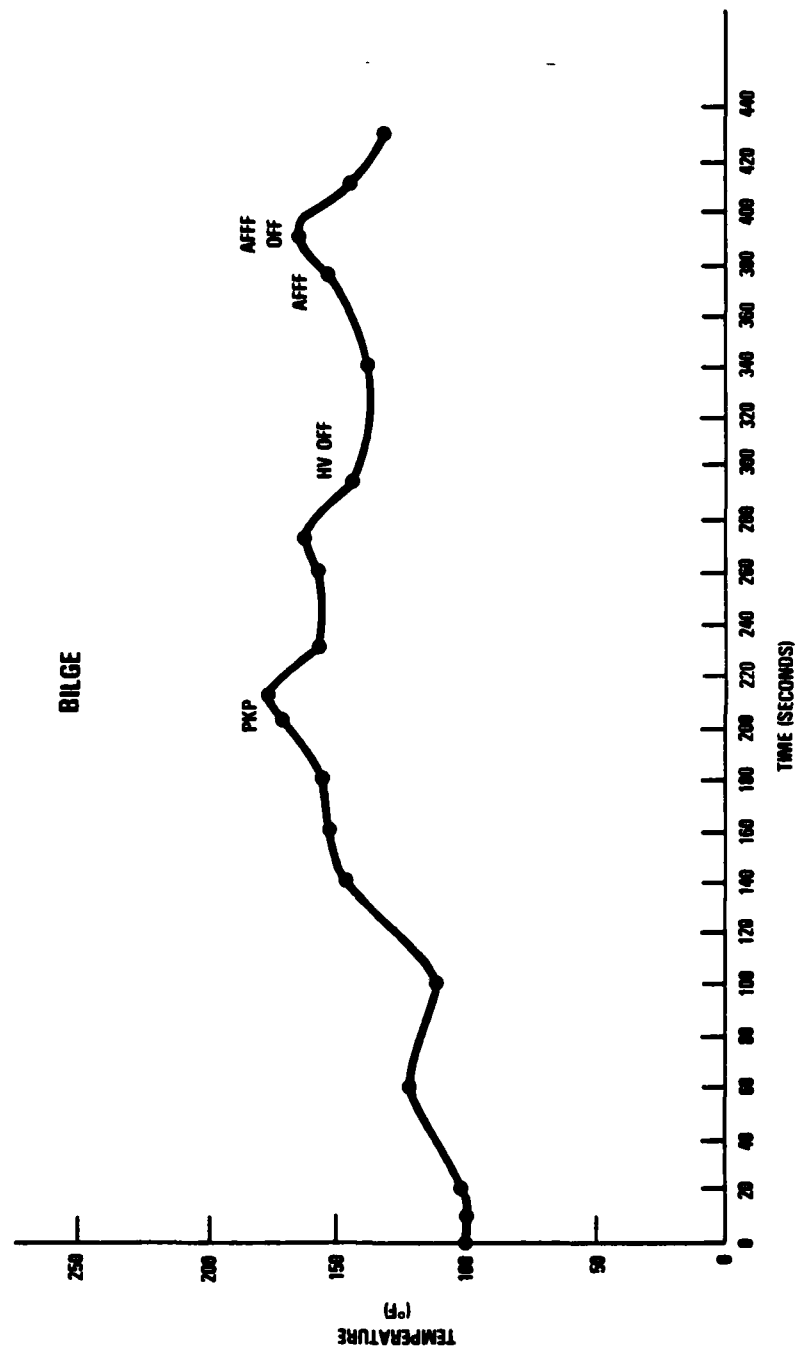Thermocouple No. 1

Figure 50. LDQI Scenario - Typical Temperature Profile
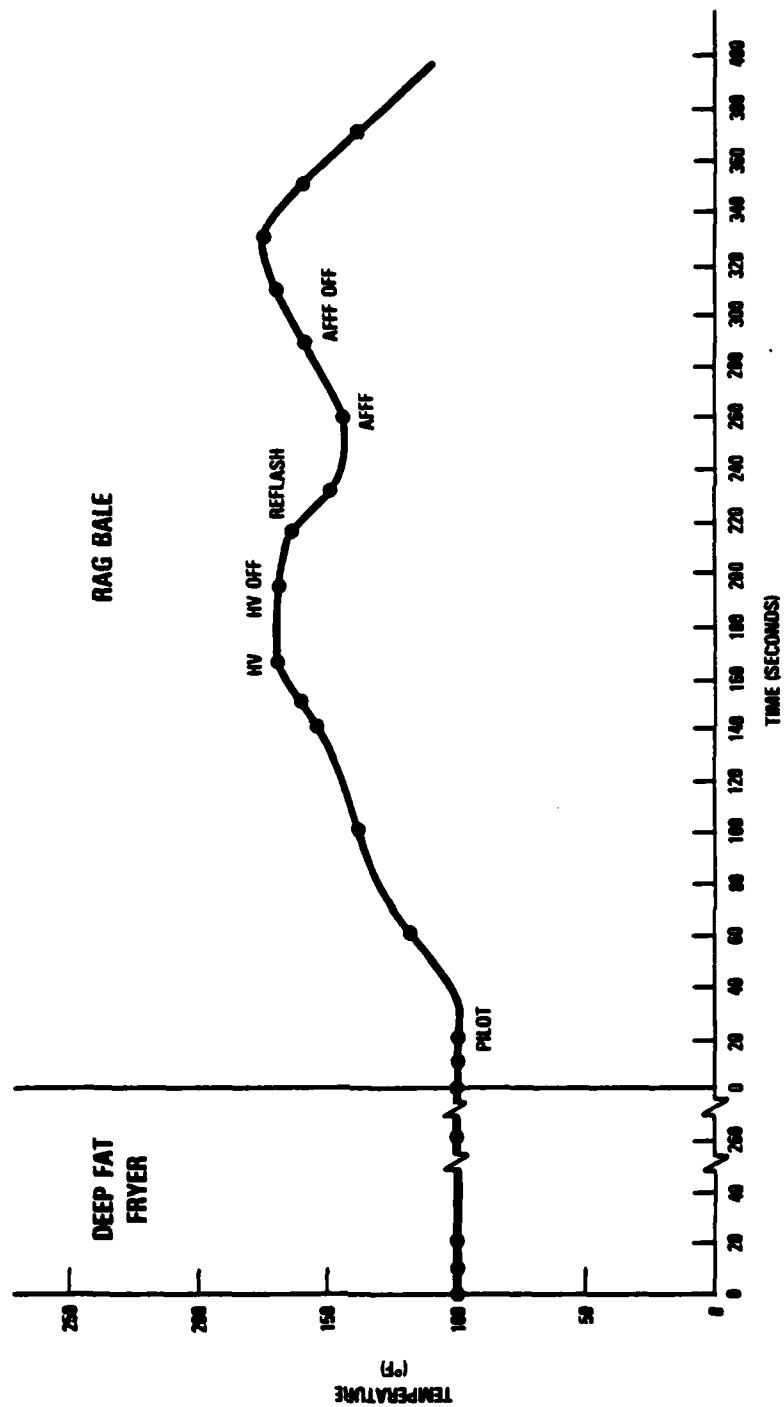Thermocouple No. 2

Figure 51. UDOII Scenario - Typical Temperature Profile
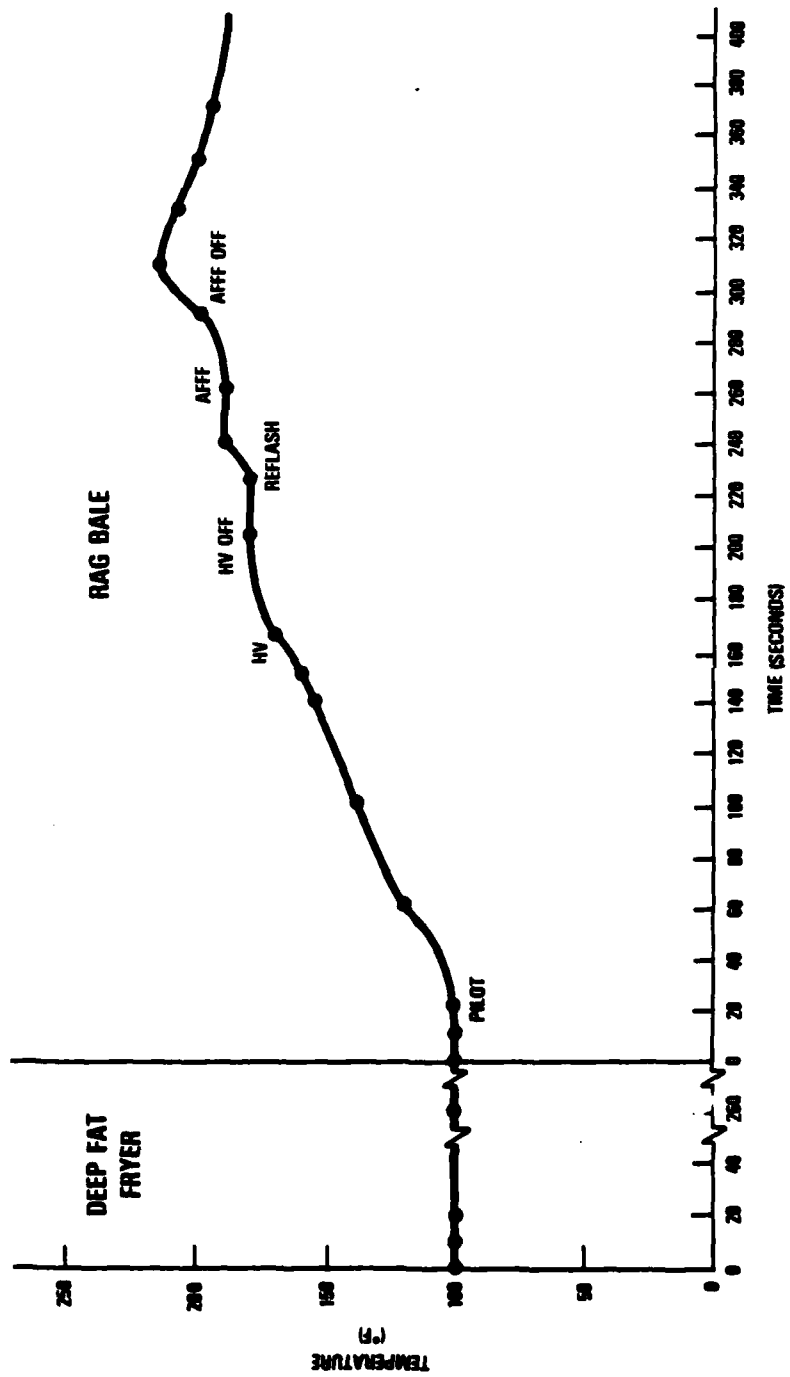Thermocouple No. 2

Figure 52. UDQII Scenario - Typical Temperature Profile
Thermocouple No. 6

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- Hydrocarbons--Concentrations follow a bimodal pattern with an increase after powder application and a greater increase during application of the high-velocity spray.

- NO_x--Concentrations show a slight increase at pilot initiation and a significant continual increase throughout application of the powder, solid stream, high-velocity spray, and foam. Concentrations rapidly decrease following termination of the high-velocity spray.

4.5.1.2 Deep fat fryer (UDQII). The profile characteristics are as follows:

- CO--Concentrations increase as the fire spreads to the hood, and they continue to increase throughout application of the low-velocity fog and powder. Concentrations rapidly decrease following termination of the powder.

- CO_2--Concentrations follow a bimodal pattern with an initial increase as the fire spreads to the hood and the second increase after termination of the low-velocity fog, which continues through the powder application.

- O_2--Concentrations show a single decrease when the fire spreads to the hood, and they remain slightly depressed throughout the remainder of the scenario.

- Hydrocarbons--Concentrations show an increase upon application of the low-velocity fog and continue to increase through termination of the powder application.

- NO_x--Concentrations show an increase upon application of the low-velocity fog and continue to increase through termination of the powder application.

4.5.1.3 Rag bale (UDQII). These raw data exhibited a large variation between the ATS and Booz, Allen readings because our detectors were closer to the fireplace than the ATS sensors. Hence, we obtained higher readings from our equipment. The composite profile was drawn to characterize the activities, although the concentration estimates will be more variable than for the other scenarios.

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The profile characteristics are as follows:

- CO--Concentrations follow a bimodal pattern with increases after application of the high-velocity spray and again after foam application.

- CO_2--Concentrations follow a trimodal pattern with a significant increase at pilot initiation followed by secondary and tertiary increases at application of the high-velocity spray and the foam.

- O_2--Concentrations show two minor decreases: an initial one at initiation of the pilot and another upon application of the high-velocity spray.

- Hydrocarbons--Concentrations follow a bimodal pattern with an increase after initiation of the high-velocity spray and a second increase after foam application.

- NO_x--Concentrations follow a bimodal pattern with an increase after the initiation of the high-velocity spray and a second increase after foam application.

4.5.2 Profile summary: gas flows/activities. The profiles of typical gas flows to each fireplace versus the scenario activities are presented by quadrant scenario in Figures 47 and 48, and are discussed in the following sections.

4.5.2.1 Oil bilge fire (LDQI). The flow rate follows a trimodal pattern, with an increase upon application of the low-velocity fog and secondary and tertiary increases at reflashes following application of the powder and the high-velocity spray, respectively. The maximum primary air flow for the burners is 6 to 8 cubic feet per minute (cfm) at an air-to-fuel ratio of 12:1.

4.5.2.2 Deep fat fryer (LDQII). The flow rate increases at initiation of the main flame and continues to increase through termination of the low-velocity fog.

4.5.2.3 Rag bale (UDQII). The flow rate follows a bimodal pattern. The first increase occurs at initiation of the main flame and then decreases upon application of the high-velocity spray. A second increase occurs during the reflash period following spray termination, followed by a decrease with foam application.

4.5.3 Profile summary: temperature/activities. Figures 49 through 52 highlight typical temperature profiles observed at specific locations near each fireplace, as

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indicated in Figures 15 and 16 in Chapter 3. Tables 19 and 20 in Chapter 3 summarize the maximum temperatures detected by each sensor for each run, and the time that this temperature was recorded during the run.

4.5.3.1 Oil bilge (LDQI). The typical temperature profile shows a steady increase from initiation of the pilots through termination of the powder application, decreasing with the high-velocity spray application. A second increase occurs after termination of the high-velocity spray and continues through termination of the foam application.

4.5.3.2 Deep fat fryer (UDQII). The temperature remained at a constant minimal level regardless of scenario activity.

4.5.3.3 Rag bale (UDQII). The temperature profile at Location No. 2 (Figure 51) shows a steady increase from initiation of the pilots through the application of the high-velocity spray, followed by a second increase with foam application continuing after termination of the scenario.

The temperature profile at Location No. 6 (Figure 52) shows a steady increase from the initiation of the pilots through the entire scenario, gradually decreasing after termination of the scenario. Location No. 6 reflects dissipation of heat from the quadrant as opposed to Location No. 2, which is closer to the fireplace.

5.   RECOMMENDED MODIFICATIONS TO THE 19F1 TRAINER

The results of the onsite sampling and chemical analysis
tasks, combined with the environmental, health, and safety
assessments described in Chapter 4, have focused on the
potential of the trainer to comply with applicable regulatory
constraints. This chapter presents recommended modifications
to the facility which, if implemented, could greatly enhance
the compliance status of the 19F1 AFFT.

5.1 Extinguishing agents. The recommended substitute
extinguishing agents and reasons for their recommended use are
discussed in the following sections.

5.1.1 Foams. Based on the results of our comparative
evaluation of foam candidates, and the positive results with
the selected optimal candidate during operational onsite field
tests, Booz, Allen recommends Ultrawet K as the optimal
surfactant currently available for use as a foam in the 19F1
AFFT. Our study has shown that Ultrawet K has the following
advantages:

- Operationally suitable for use in the trainer

- Environmentally compatible with the use of proper
  disposal procedures such as biological treatment

- Relatively nontoxic

- Cost-effective for use in the trainer.

Ultrawet K is much more cost-effective and is safer to health
and the environment than AFFF, the foam originally proposed for
use in the trainer.

Future research and development in surfactants may
eventually uncover a more compatible product with less aquatic
toxicity than current foam products. However, Ultrawet K is
the optimal surfactant available at this time.

5.1.2 Powders. On the basis of our comparative evaluation
and onsite field tests with candidate powders, Booz, Allen
recommends a coarse powder of sodium bicarbonate that is
treated for use as an extinguishing agent as the optimal powder
for use in the 19F1 AFFT. Our study has indicated that this
processed powder has the following characteristics:

- Operationally suitable for use in the trainer

- Comparatively less diffusive and corrosive

- Environmentally compatible with proper disposal treatment

- Relatively nontoxic

- Cost-effective for use in the trainer.

A processed coarse sodium bicarbonate powder is commercially available and is cost-effective. It is less diffusive than the fine PKP powder originally proposed for use in the trainer. The coarse sodium bicarbonate powder is also less corrosive than PKP.

Future research may find a better product that is less corrosive, less irritating upon dermal exposure, and more readily disposable. Presently, a processed coarse sodium bicarbonate powder is the optimal powder available for the AFFT.

5.2 Simulated smokes. Based on the evaluation of competing simulated smoke candidates, and the favorable results of our onsite field testing, Booz, Allen recommends that triarylphosphate (Chem Chex 220, a butylated triphenyl phosphate) be considered as the optimal material currently available for use as an obscuring simulated smoke in the 19F1 AFFT. Future research may reveal another material or mixture of materials possessing more favorable characteristics than TAP; however, we believe that TAP is the optimal material for use at the present time. This recommendation is for the specific material stated above, as other triarylphosphates could be far more toxic (e.g., triorthocresylphosphate).

We recommend that the smoke-generation system be suitably modified to provide the following:

- Quieter operating unit

  - Electric motor rather than gasoline powered
  - Propane-powered burner
  - Noise-suppression panel enclosures
  - Permanent mounting

- Better delivery system into the trainer facility

  - Direct piping to required quadrants
  - Separate solenoid valve controls for quadrants.

In addition, we recommend that a field evaluation of a smaller model of the commercially available smoke generator be made to determine its cost-effectiveness over the current model used during the onsite sampling program.

Booz, Allen would not recommend prolonged smoke generation beyond the minimal time requirements for effective training; the primary concern was a visual emission problem, and the secondary concern was the expense of excessive material usage.

5.3 <u>Ventilation</u>. Ventilation is the widely accepted engineering control for reducing potentially toxic and/or flammable internal atmospheric conditions. Ventilation requirements for the fire fighter trainer necessitate both control of the internal atmosphere by general and/or local exhaust ventilation and dilution ventilation for the purposes of fire prevention. Concentrations within the exhaust ventilation system should not exceed a safe fraction of the lower explosive limit (LEL). Careful scrutiny of emission concentrations is necessary to properly evaluate the current system's modification requirements.

Booz, Allen recommends that the ventilation system for the trainer be considerably upgraded to provide sufficient quantities of air to reduce the potential hazards to both health and safety.

5.3.1 Exhaust ventilation. NIOSH recommends that the maximum concentration of the exhaust from a confined space be no more than the permissible exposure limit (PEL) and/or 10 percent of the LEL, whichever is lower. Redesign of the current ventilation system is necessary. Obviously, in redesigning the ventilation system, the total output of material may remain about the same, but the concentration is reduced. NIOSH also recommends that continuous general ventilation be maintained where toxic atmospheres are produced or may develop due to the nature of the confined space. Booz, Allen completely supports this concept and recommends that exhaust ventilation be operating continuously throughout all training exercises. Furthermore, NIOSH suggests local exhaust ventilation be provided where general ventilation is not effective.

5.3.2 Dilution ventilation. Dilution ventilation can be used to reduce explosion potentials by reducing internal atmospheric concentrations of propane. Dilution ventilation is never applied for reducing concentrations below the LEL where personnel health might be affected. Dilution ventilation requirements can be estimated based on the data from the sample chemical analyses performed as summarized is Section 4.3.2. Because the use of self-contained breathing apparatuses are an integral part of the training program, human exposure is not the major determining factor.

5.4 <u>Pollution Control</u>. As mentioned in Sections 4.1.1 and 4.1.2, the 19Fl trainer operation has several aspects that might potentially result in noncompliance with air and water pollution control regulations. These areas are addressed in more detail in the following subsections, and recommendations are made for potential modifications to the 19Fl that would reduce or eliminate the risk of noncompliance.

5.4.1 Air pollution control. The recent test results indicated that the primary air contaminant problem will be visible emissions during exhaust of the triarylphosphate smoke. It is not clear from the available data what level of particulate emission reduction would be necessary to meet current opacity standards if a regulatory body requires it. Should emission reductions of more than 95 percent be required, sophisticated control equipment, such as a 2-stage low-voltage electrostatic precipitator, would probably be necessary.

The precise method of control will require an evaluation of the emissions' aerosol size distribution. This size analysis was beyond the scope of the current assignment. The electrostatic precipitator would have the greatest control capability for the smallest of particulates (as small as 1 micrometer); however, individual states may not require this high control level, permitting other emissions-control options such as cyclone separators and baghouse filters, assuming their efficiency was adequate for the size aerosol to be generated.

5.4.2 Wastewater pollution control. As discussed in Section 4.1.2, there are three potential problems associated with the discharge of AFFT effluents to a local sewage treatment plant. These problems are extraordinary flow variability, excessive biodegradable surfactant concentrations, and wastewater pH/alkalinity. Pretreatment of AFFT wastewaters may be necessary to mitigate these potential problem conditions prior to discharge.

Equalization of wastewater flows prior to discharge serves to dampen the hydraulic surges which, without attenuation, could cause upsets or reductions in treatment efficiency at the local treatment plant. Some of the key factors that should be considered in the design of a flow equalization system include the following:

- Optimum location of the system
- Optimum volume required for equalization
- Type of construction
- Aeration and mixing equipment
- Pumping and discharge flow rate control.

Equalization volume is typically based on the maximum variation in 24-hour flow expected. The basins may be constructed of earth, concrete, or steel; earthen basins are generally the least expensive. Aeration and mixing equipment is required to blend the contents and to prevent deposition of solids in the basin. Submerged diffused aeration systems or surface mechanical aerators are available for this purpose. Uniform flow discharge may be accomplished by pumping or by gravity depending on the basin location relative to the sanitary sewer.

The reduction of biodegradable surfactant concentrations in the AFFT effluents may also be required at some sites. This can probably be most effectively achieved by incorporating biological treatment capabilities into the design of the equalization basins.

Normally, some removal of biodegradable organics is likely to occur in an aerated equalization basin. Consequently, if special attention is given to providing optimum conditions for microbial growth and utilization of the organic sufactant, such as providing adequate basin detention time and aeration requirements, additional removals should be achievable while the basin continues to function to smooth flows. To prevent foaming problems that might occur due to the aeration of surfactant wastewaters, commercially available antifoams could be added. Also, it might be necessary to provide a mechanism for removing the biological solids that are produced in the basin as a result of surfactant removals.

Solids will, at minimum, need to be removed so concentrations in the discharge do not exceed those allowable under the industrial discharge standards. A clarifier or settling basin following the aerated equalization basin would satisfy this need. If solids-removal equipment is provided, attendant capability to dispose of the removed solids, or sludges, will be necessary.

Finally, it may be necessary to adjust the pH of the AFFT wastewater streams downward to within the allowable ranges established by the various industrial discharge standards. In addition, pH reduction would also be desirable for the purpose of maintaining optimum microbial growth conditions (pH of 6 to 8) for organics removal in the aerated equalization basin.

The depression of pH may be accomplished through the use of acid. The acids that may be used in wastewater neutralization are sulfuric (H_2SO_4), hydrochloric (HCl), and nitric (HNO_3). A simple drip or siphon apparatus could be used to constantly apply acid to the influent line to the equalization

basin. The amount of acid required to reduce the pH to intended levels will be proportional to the amounts of carbonate and bicarbonate ions present.

5.5 <u>Gray water recycling</u>. The recycling of AFFT effluents for reuse in the fire fighter training exercise may be a desirable alternative to disposal of wastewaters at some locations. In order to reuse the AFFT effluents, the basic chemical components that were added during the fire fighter training activity need to be removed so as to produce a reusable or gray water. Where fresh water supplies are restricted or expensive, the economics of gray water production and recycling should be compared with the alternative of once-through water use and subsequent disposal to determine the desirable course of action.

The production of a reusable gray water requires the removal of the Ultrawet K surfactant and the various dissolved ions (carbonates, bicarbonates, sulfates, various cations, etc.). Activated carbon is the best developed and one of the most efficient processes available for removal of organic materials and some inorganic materials from wastewater. Surface active compounds like Ultrawet K are especially well suited for removal via granular carbon adsorption.

A possible mode of operation for AFFT effluent treatment would be to run the wastewater through a column of granular activated carbon. The addition of acid prior to carbon treatment would serve to remove carbonate and bicarbonate alkalinity by conversion to carbon dioxide. In addition, this would reduce the pH of the wastestream to more efficient levels needed for surfactant removal in the carbon adsorption step.

The remaining dissolved solids in the effluent from the carbon columns would probably be most effectively removed by reverse osmosis, a membrane process that has formal applications in demineralizing brackish waters. Reverse osmosis units have achieved stable operation, particularly when preceded by carbon adsorption. Reverse osmosis membranes remove a high percentage of almost all inorganic ions as well as any remaining organic material present.

It is important to note that several cycles of gray water reuse can result in the development of excessive concentrations of certain chemical constituents that are not completely removed during treatment. Consequently, a predetermined fraction of makeup water must be added to the recycled gray water through each pass through the operation.

The above discussion represents only a preliminary assessment of the potential for gray water reuse in AFFT operations. Because of the many uncertainties associated with the efficacy of reuse, detailed wastewater treatability studies should be undertaken to properly evaluate the effectiveness of selected treatment operations and processes in treating the AFFT effluents to the degree necessary for reuse.

5.6 <u>Powder extinguishment sensor modification</u>. During the onsite pretests a question arose concerning the ability of the sodium bicarbonate proposed for use as a PKP surrogate to activate the PKP sensor in the deep fat fryer. This sensor, unlike the one in the oil bilge that sensed flame suppression, was activated by the extinguishment cloud density.

Booz, Allen suggests that consideration be given to replacing the sensor with one that could detect and discriminate the clearly defined sodium lines produced when the sodium bicarbonate mixes with the open flame. This would appear to be a more efficient and reliable sensing mechanism.

ATS is currently evaluating a sensing unit capable of this sodium discrimination. Assuming this sensor can be readily developed, we recommend that it be used in lieu of the currently used opacity sensor.

6. OTHER RECOMMENDATIONS AND CONCLUSIONS

The 19Fl Advanced Fire Fighter Trainer can be operationally feasible once appropriate modifications outlined herein are made including the use of recommended training materials and the environmental data base is reviewed with the proper regulatory and permitting agencies. In order to focus on the major issues identified in this study, this chapter summarizes and highlights our key conclusions with our recommendations. The assessments and recommendations made are based on "worst case" scenarios developed for the purpose of conducting an evaluation to simulate possible training activities when the facility is in operation. The actual training activities will vary from these scenarios. Therefore, unlike the predictions that could be made for a specific industrial process, the trainer will require monitoring of the initial parameters of concern after the trainer is operational to characterize the actual effluent. The data already collected are an indication of the environmental characteristics that will most likely require follow-up monitoring as will probably be required by the discharge permits obtained.

6.1 <u>Regulatory constraints</u>. The regulatory constraints affecting the 19Fl include those of the Environmental Protection Agency (EPA), the National Institute of Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), the Naval Environmental Health Center (NEHC), and the Naval Safety Center (NSC). We recommend the following:

- Complete compliance to the strictest recommended criteria

- The Navy monitor the publications of the regulatory bodies to monitor changes in recommended constraint guidelines.

6.2 <u>Health and safety</u>. The internal conditions of the operating 19Fl AFFT, using the recommended material changes, remain deleterious to human health from inhalation exposure to toxic materials and possibly internal heat. We recommend the following:

- All personnel in the operating trainer wear an oxygen-breathing apparatus or a self-contained breathing apparatus to protect against inhalation of high concentrations of toxic materials.

- All personnel in the operating trainer wear appropriate apparel (as currently prescribed) to protect against burns and skin absorption of toxic materials.

- Noise-suppression controls be applied to the smoke-generating equipment.

- Special attention be given to the potential health hazards of instructors who will generally be at greatest risk.

  - Instructors' work practices should be significantly improved, and enforcement of proper practices must be strong.

  - Medical surveillance should be provided to monitor such physiological parameters as pulmonary function and metabolism as well as overall general health of individuals being chronically exposed to potentially toxic agents (both physical and chemical).

There are several safety concerns related to training. We recommend the following:

- Triarylphosphate (a butylated triphenyl phosphate equivalent to Chem Chex 220) be used to generate a simulated smoke during training exercises.

- Assured egress in emergency situations be maintained at all times by properly marked exits and by exit doors that are operable from the inside.

- The currently installed environmental monitoring system be modified to broaden the detection ranges recommended.

- Adequate maintenance procedures be followed to reduce slipping hazards from wet surfaces that become coated with foam extinguishments. Facility washdowns between exercises are optimal.

- Further evaluation be made as to the utility of replacing the current powder extinguishment sensors with sodium detection sensors.

There remains a potential for an explosion of excess propane accumulated during the trainer operation. We recommend that the exhaust ventilation system be redesigned to increase airflow through the facility and to reduce internal propane concentrations. The recommended goal would be to meet NIOSH criteria for confined spaces as a minimum. In addition, increased ventilation would decrease internal contaminant concentration and increase oxygen levels.

6.3 Temperature stress. The internal temperatures observed in the operating trainer have raised specific concerns regarding heat stress of trainees and the criteria for functional equipment operation. We recommend the following:

. Supervisors be alert to episodes of heat stress during training activities and to the fact that protective apparel will exacerbate the problem and that trainees will be more susceptible than instructors.

. Adequate supplies of water and salt be made available to trainees.

. Trainees be briefed prior to training exercises on the symptoms of heat stress.

. A work-rest regime be developed to limit internal heat exposure periods. The work-rest regime is determined by the time the individual is working versus resting time and the location (and associated temperatures at that location) at which the activity is being performed.

. Additional measures be taken for further reduction of operating temperatures of the trainer by:

- Further development of the water fog cooling techniques preliminarily tested during the onsite sampling program

- Increased ventilation to convectively reduce heat load.

6.4 Environmental. The Phase I report identified several major concerns regarding air emissions, wastewater effluents, and solid waste disposal associated with operation of the 19F1 AFFT. The recommendations presented in this Phase II assignment have essentially resolved those issues.

The major air pollution concern identified in the Phase I study was the emission of particulates resulting from the use of PKP. We have alleviated this emission problem by recommending a substitute powder, sodium bicarbonate grade No. 2. The recommended powder has a larger particle size, causing rapid settling and, therefore, significantly reduced particulates emissions as compared with PKP.

The recommended smoke in this study, triarylphosphate, produces visible emissions during exhaust that may or may not be acceptable depending on the requirements of the particular

regulatory agency involved. If emissions need to be reduced, possible control options would include use of an electrostatic precipitator, cyclone separator, or baghouse filter depending on the relative efficiency of handling the size aerosol generated (estimated to be between 0.5 and 2.0 micrometers).

Wastewater effluent problems associated with the proposed use of AFFF were identified in the Phase I report. Because AFFF was not acceptable for use in the AFFT, we have recommended Ultrawet K as the foam substitute. Ultrawet K is far less expensive, thus, more cost-effective for training than AFFF, and it alleviates the water pollution problems associated with AFFF.

The wastewater effluent measured containing Ultrawet K appears to be within acceptable standards for discharge to treatment facilities in virtually every state with the possible exception of California. Depending on the specific operational requirements of the local wastewater treatment plant, there may be three potential concerns associated with the discharge of AFFT effluents:

.   Extraordinary flow variability
.   Excessive biodegradable surfactant concentrations
.   Wastewater pH alkalinity.

If any of these situations arise, they can be alleviated by pretreatment of the wastewater prior to discharge. We have suggested several pretreatment methods if they are needed. These methods are described in the remaining portion of this section.

Equalization of wastewater flows prior to discharge diminishes hydraulic surges which, if not checked, could reduce the efficiency of water treatment at the local treatment plant. A uniform flow discharge can be achieved by pumping or by gravity depending on the location of the basin relative to the sanitary sewer.

Specific treatment facilities might require a reduction of the surfactant concentration of the AFFT effluent. This can be achieved by biological treatment in an aerated equalization basin. To prevent foaming due to aeration of surfactant wastewaters, commercially available antifoams could be added. Antifoams such as Arquad 26-75 and Silicon Antifoam SWS-214 are two available products that can be used to eliminate foaming should it present a problem. The former material (available from Armak Company, Chemical Division, McCook, IL) is itself a surface-active agent and if too much is added it, too, will cause foaming. The latter material (available from SWS Silicon

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Corporation, Adrian, MI) is an extremely effective antifoam requiring only small quantities in practice. The optimal material and concentration can be best determined only by experimentation. Additional information on foam control can be obtained from L. A. Kern (operates fire fighter training at Chanute AFB) at (217) 495-4133 or Mr. John DiLoreto (Pretreatment Unit Supervisor, Washington Suburban Sanitary Commission, Laurel, MD) at (301) 495-4355. The biological solids produced in the basin as a result of surfactant biodegradation could be removed in a settling basin. Disposal of Ultrawet K does not produce a hazardous solid waste problem.

The use of the recommended powder sodium bicarbonate No. 2 in the AFFT produces an alkaline pH of the effluent that is near the acceptable limit for some states. In case pH control is necessary for a specific wastewater treatment plant, we recommend that the pH be neutralized by adding a sufficient amount of acid that is proportional to the amount of carbonate and bicarbonate ions present. The reduction of pH would also be beneficial for maintaining optimal microbial growth conditions (pH of 6 to 8) for organics removal of Ultrawet K in the aerated equalization basin.

Depending on cost-effectiveness and water availability considerations, an alternative to wastewater disposal is the recycling of AFFT effluents for reuse in the trainer. To reuse the AFFT effluents, the basic chemicals added during the fire fighter training procedure must be removed to produce a reusable or gray water. Hence, the Ultrawet K surfactant and various dissolved ions (e.g., carbonates, bicarbonates, sulfates, and various cations) would need to be removed.

Addition of acid to the AFFT wastewater would remove carbonate and bicarbonate alkalinity by conversion to carbon dioxide. Ultrawet K could then be removed by granular carbon adsorption. The remaining dissolved solids in the carbon columns could be removed by reverse osmosis. Because several cycles of gray water reuse can result in excessive concentrations of certain chemical components not completely removed during treatment, possibly interfering with proper sensor detection, it would be necessary to dilute the gray water with fresh water during each treatment.

6.5 Cost effectiveness for training. There are specific economic advantages to using the recommended alternative materials in the 19F1 AFFT. The Navy's projected material use for a 2-day curriculum course is 300 gallons of foam concentrate and 600 pounds of dry powder. Assuming two classes are held simultaneously (one in each half of the facility), with two training sessions per week, the annual material

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consumption for one training facility would be approximately 60,000 gallons of foam concentrate (6 percent AFFF) and 120,000 pounds of dry chemical powder (PKP). A comparison of the retail prices for each material and the recommended substitute is shown in Table 28.

The actual savings to the government will be proportionately less based on the specific negotiated prices, but the overall cost-reduction represents a 93-percent savings. This savings is further amplified by the material usage at the other proposed AFFT sites.

6.6 <u>The 19F1 AFFT compared to older trainers</u>. To place this analysis in perspective, some comments about the currently used fire fighter trainers are in order. Any comparisons made between the 19F1 and older confined space trainers are essentially based on minimal data and objective evaluation based on direct observation.

The 19F1 has several clear advantages over the older trainer. These advantages include the following:

- Acceptable atmospheric emissions rather than thick, dense, lingering black plumes

- Immediate shut-down control of all fires in emergency situations including

    - Excessive hazard potential from gas buildups
    - Safety problems such as trainees being injured

- Realistic and consistent fire behavior that can be controlled

- Sensing equipment to detect proper extinguishment application type and duration

- An acceptable wastewater effluent with little or no pretreatment

- A dense obscuring training smoke that is completely under operator control without associated problems of real smoke.

A study of the older trainers identified approximately 45 compounds (aside from gases), including approximately 17 aromatics and several carcinogens. The AFFT propane-operated devices are cleaner burning and, hence, avoid potential exposures to these compounds.

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TABLE 28

MATERIAL COST COMPARISONS FOR ONE AFFT SITE

Material	Total Annual Use	Retail Unit Cost	Total Annual Cost	Reduction Using Substitute
AFFF	60,000 gallons	$22.00/gallon	$1,320,000	--
PKP	120,000 pounds	$ 0.65/pound	$ 78,000	--
Ultrawet K	48,000 pounds	$ 0.75/pound	$ 36,000	97 Percent
Sodium Bicarbonate	120,000 pounds	$ 0.50/pound	$ 60,000	23 Percent

Both units require the trainee to perform in an intense
heat environment. Although no data are available on the
operating temperatures of the older trainer, it is assumed that
comparable or even greater temperatures can be reached. The
risk potential for heat stress is ever present in either
trainer.

The many advantages of the 19F1 AFFT for training in
confined space make it highly attractive for fleet-training use
from both a training and especially an environmental viewpoint.